Cellular IoT Devices 2019

Abstract: This document provides technical and cost comparisons for 2G, 3G, 4G, and 5G IoT devices, as well as a thorough review of existing cellular IoT business as it shifts from GSM/GPRS to LTE-M, NB-IoT, and 5G IoT. Market share, shipment, pricing, and revenue data are included with a ten-year forecast for growth in key areas.

January 2019

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1 EXECUTIVE SUMMARY

The market for autonomous cellular-based wireless devices has now made a pivot from the old M2M formats (2G, 3G, and early LTE), as we now see the more rapid growth trend of Cellular IoT (C-IoT). The fundamentals have changed:

- The old mentality of "use the broadband network for a little extra revenue" has now shifted, with some operators deploying base stations simply for IoT.
- New technologies allow for much lower power consumption and therefore longer battery life, making some new applications possible.
- Cost is coming down quickly, with simplified and optimized products coming to market.
- The Chinese government is subsidizing NB-IoT heavily and this is sparking major growth in China.

Note that Mobile Experts has changed its forecast horizon from five years to ten years in the IoT market, because almost all of the important vertical markets operate on longer time scales than the rapid-fire mobile market.

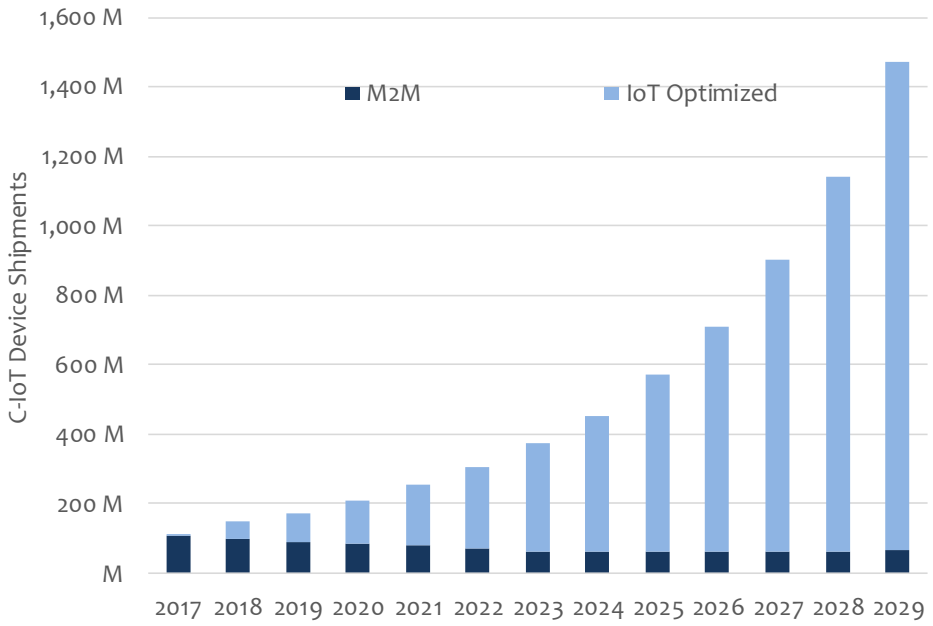


Chart 1: Transition from M2M to Cellular IoT Device Shipments, 2017-2029

Source: Mobile Experts

Note: M2M includes 2G, 3G, and LTE through LTE Cat-1. "IoT Optimized" includes LTE-M, NB-IoT and 5G IoT

Growth in this market will be rapid at multiple layers of the market. Specifically,

- IoT Device shipments will grow by a CAGR of 23% through 2029. In the short term, NB-IoT growth will be greater than 100% per year, but over a ten-year period, we expect NB-IoT and Cat-M to settle into the 24-41% growth range.
- IoT Service Revenue will grow by 19% CAGR through 2029, with low pricing offsetting the rise in volume for mobile operators. After 2025, we believe that the IoT market will finally become significant to operators with premium devices kicking the market into the range of hundreds of billions of dollars.
- IoT Module revenue will grow at 14% CAGR through 2029.
- IoT Semiconductor revenue will grow at 10% CAGR as well.

Notably, the hype surrounding 5G IoT devices does not appear justified in the near term, but premium low-latency, high reliability applications may become significant after 2023. Overall, the big story is that LTE-M and NB-IoT will expand to more than 1 billion units per year over time, creating a new large, sustainable market for modules and chipsets.

2 MARKET DRIVERS FOR C-IOT

Over the past four years, Mobile Experts has investigated eight individual vertical markets for Cellular IoT—so that we could finally make some general conclusions about the IoT market. Each individual market is driven by different forces and each market area has challenges in regulatory, business model, or technical areas that will slow down the potential growth.

ENTERPRISES ARE PULLING THE IOT MARKET

As a whole, the Cellular IoT market is driven by enterprise demand. Consumer use of devices remains scattered, but enterprises are starting to find reasons to instrument their equipment with sensors and automate processes that were previously handled by human workers.

Another important point is that enterprise C-IoT applications drive much higher pricing than consumer applications, for the same functionality. A "pet tracker" carries very little monthly service revenue, but asset tracking in a fleet-management scenario can drive 20-100X higher revenue per month.

In particular, applications that require tracking sensor data over widespread areas, or for moving objects, needs IoT connectivity to enable the basic automation. Examples include:

- Electric utilities that need sensors on high-voltage transmission lines over hundreds of miles need long-range NB-IoT or similar connectivity.
- Oil well monitoring such as pressure, temperature, and tank levels can be critical for energy companies. Simple sensors can eliminate hours of technician time to drive around the oil field.
- Smart "trash cans" can notify technicians when they're full or empty, to improve efficiency for the truck drivers.
- Cars with advanced telematics can drive higher revenue in service at the dealership, or provide useful data to insurance companies.

There are many other examples, but the common theme is that IoT sensors can eliminate wasted time for employees by reducing the time spent on "go over there and check". We call this "Information Automation".

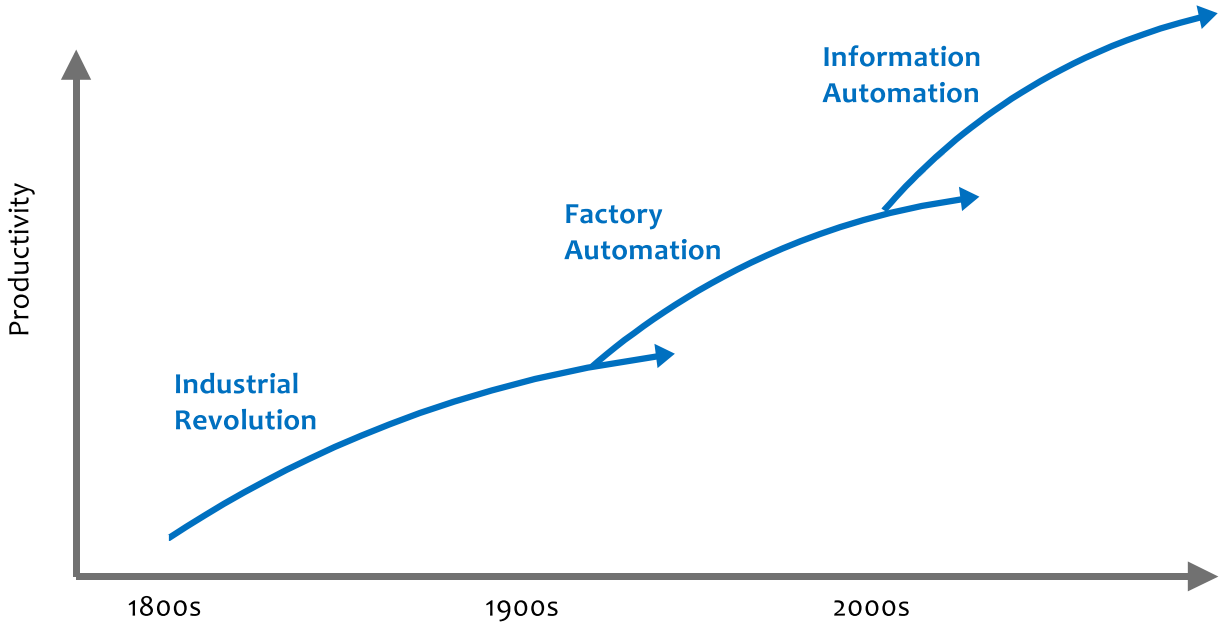


Figure 1 Information Automation: Improving Enterprise Productivity

Source: Mobile Experts

In addition to labor saving costs, IoT devices can enhance enterprise productivity. Drones can, in some places, deliver more packages per hour than a human driver, because traffic is simply not a factor. Factories can be reconfigured quickly with wireless robotic controls, reducing downtime. Predictive maintenance can eliminate failures for higher productivity.

Overall, enterprises have two reasons to invest in IoT: Reduced costs and higher productivity.

OPERATORS ARE PUSHING THE IOT MARKET

So, enterprises are "pulling" for IoT devices. At the same time, operators are "pushing" the IoT in an attempt to sell services to major enterprises. The operators aren't very good at selling to the business market, but their efforts are helpful in educating IT professionals on the possibilities.

Almost all operators worldwide are looking to the IoT as a new source of service revenue. However, over the past four years many operators have realized that IoT revenue will remain a small percentage of broadband revenue, so we can already see the focus shifting. A few mobile operators have invested in new network equipment or other major platforms, but most operators are simply trying to re-use their broadband network to make a little extra revenue on IoT.

Even the most successful mobile operators achieve less than 2% of total revenue from IoT connectivity. This could change over the longer term, but we see the transition as a slow change. In the long run, connectivity will not drive meaningful revenue for operators, but overall IoT services or cloud hosting could reach hundreds of billions of dollars annually.

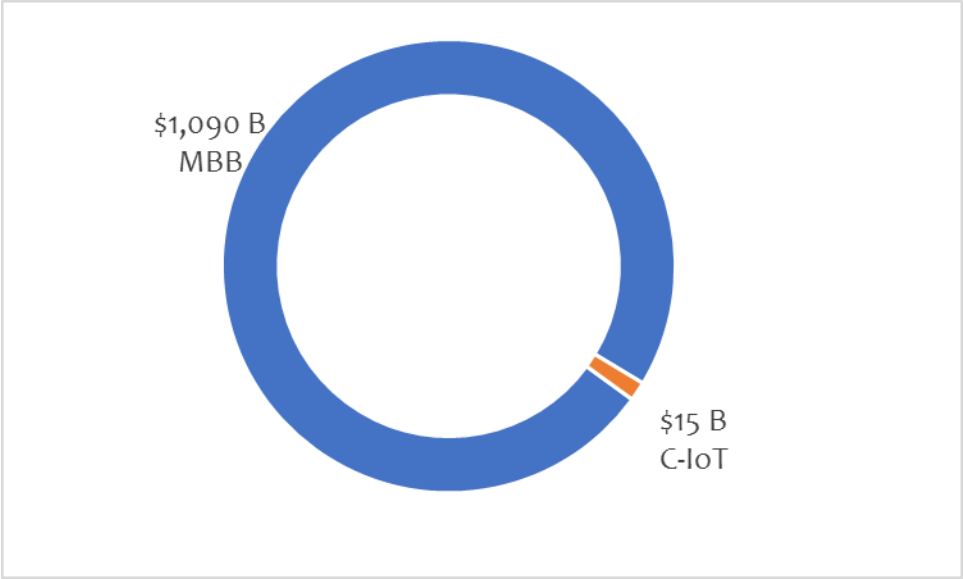


Figure 2 Mobile Broadband and C-IoT Revenue for Operators in 2018

Source: Mobile Experts

Over time, the installed base of IoT devices will grow, so we anticipate C-IoT connectivity revenue could grow into the range of 5-10% of total operator service revenue. Significant, but not necessarily a stand-alone business. Most operators now recognize this reality, and are starting to think of how they can adapt to exploit the IoT market for other revenue.

Specifically, some operators are considering cloud services, data analytics, and other service areas in hopes of increasing IoT-related revenue. This transition is very uncertain. The operators have a big advantage in connectivity due to their existing networks and spectrum, but establishing themselves as well-recognized cloud platforms with key app development will be a challenge.

One market is different: China. Recently, the Ministry of Industry and Information Technology (MIIT) in China has pushed the three state-owned operators to set up NB-IoT networks and has heavily subsidized device and semiconductor suppliers to consolidate the Chinese IoT market onto one format. As a result, the number of NB-IoT devices in China has grown quickly over the past year. Various players in China had forecasted as many as 100 million NB-IoT device shipments in 2018. As the year closes, the operators and vendors have both become much more quiet about the actual numbers, and we see evidence for about 30 million devices in China. Strong growth, but not as strong as some had expected.

Because the government has directed network investment, low pricing, and heavy subsidies, China is moving quickly on NB-IoT. The government has given the application development vendors the certainty that they need to invest heavily in a risky business plan. We expect to see this play out in the asset tracking market, as well as a few other surprising areas such as white goods and automotive devices.

3 MARKET CHALLENGES

Despite the broad consensus for strong market growth, some major roadblocks stand in the way of cellular-based IoT technologies.

VERTICAL MARKET INERTIA:

In each vertical market, the timescales for technology decisions are much longer than consumer markets such as the smartphone market. For example, water meters are only replaced every 40 years, so adoption of a new technology can take several years to grow.

Similarly, in the streetlight market the investment decision must follow an extremely slow path, with discussions and town meetings and policy focus groups and ballot initiatives for special property tax assessments. The political process can be slightly different for each city, but the end result is that the decision can require 4-5 years before any meaningful progress can be made.

In the automotive market regulatory decisions have slowed down adoption. In the United States, ten years of development was expected to lead to a government mandate for 802.11p vehicle-to-vehicle communications in every car. However, President Trump's administration chose not to require this feature in new cars….throwing the adoption of this technology into doubt. Now, the world market for V2V modules has been delayed because of uncertainty about the US market.

LACK OF STANDARDIZATION BEYOND CONNECTIVITY:

While many different vertical markets can agree on a format such as NB-IoT, the handling of data is much more open. Dozens of platforms now compete for storing, handling, and analyzing the data itself. The fragmentation of the disparate data formats has prevented any one data format from quickly becoming a *de facto* standard so far. Instead, each vertical market appears to have its own preferred data handling/analytics engine, with little crossover for other vertical applications.

COST:

Cost is higher for C-IoT technology than for alternatives. LTE-M devices are still more expensive than Bluetooth or U-LPWA devices, in terms of semiconductor BOM cost as well as the fixed costs of the mobile operators. This will remain true for many years, due to the higher complexity and higher transmitter power of licensed C-IoT.

In China, government subsidies have brought down the cost of NB-IoT modules dramatically, so that modules are now available for less than 35 yuan ($5). LoRa and other devices can be roughly equivalent in BOM cost, so in this market NB-IoT technology has a stronger chance of attracting developers compared with LoRa and other alternatives.

DEVICE AVAILABILITY:

Two years ago, device availability was an issue in testing IoT applications. Today, hundreds of modules and variations are ready off the shelf, so we no longer see LTE-M or NB-IoT availability as a hindrance.

On the other hand, 5G networks and device availability remain a major barrier to testing and development of new low-latency applications. We don't expect 5G URLLC to take off quickly because the applications will center on new use cases that still have not been widely tested.

MOBILE EDGE COMPUTING AND CLOUD PLATFORMS:

Mobile operators have been reluctant to invest heavily in Edge Computing hardware in every radio site, because the billions of dollars required would not be recouped in today's IoT market. Instead, the operators are investing in regional data centers that achieve connection latency times in the 20-50 millisecond range. This means that any low-latency applications will need to wait for mobile operators to be convinced of the business model, then to invest in a widespread network of Mobile Edge Computing platforms.

Another wrinkle in this business model is that the operation of the cloud platform is not certain. Will the operator set up a server to operate as a "carrier cloud"? Or will the operator simply host a web-scale company such as AWS, Google, or Azure to run a globally recognized cloud platform? We believe that the cloud players will win here, so the mobile operators need to adjust their business plans to become a host, not a cloud service provider. This mental adjustment could take years for some of the big operators.

LACK OF TRUST IN MOBILE OPERATORS:

In general, mobile operators are well respected. But enterprises know that mobile operators will allocate spectrum and other resources to the mobile broadband market, and follow the consumer revenue wherever it leads. This makes a commitment to an IoT business case more risky, because the IoT market is not likely to become the mobile operator's top priority.

Mobile insiders know that modern networks are "software defined", and can handle IoT formats and broadband data at the same time. But many enterprises and their IT management don't know that this important transition has occurred. The industry needs to educate the business world about the stability of technology using software-based networks, that can handle a legacy IoT format even after the broadband business moves to the next level.

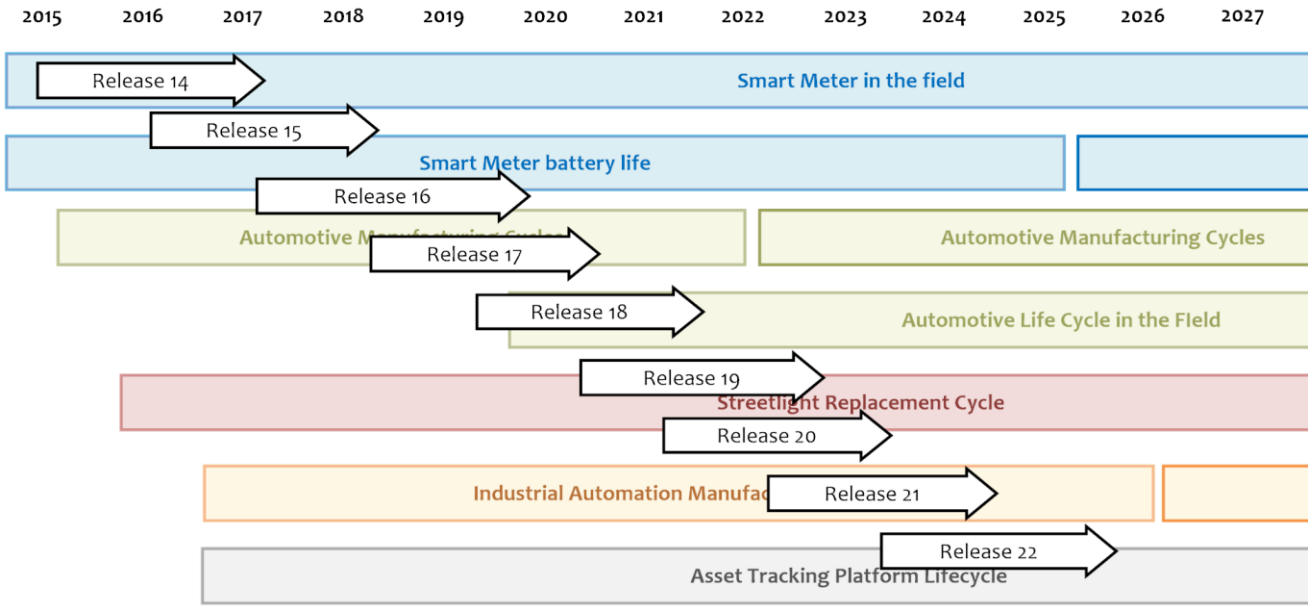


Figure 3 The Timescales of IoT Markets compared with 3GPP standards

Source: Mobile Experts

Mobile operators generally don't have strong enterprise sales teams to overcome the friction that is inevitable here. Since the telecom market is very different than individual industrial markets, the operators need to develop stronger sales skills to build up trust in key IoT markets.

4 TECHNOLOGY BACKGROUND

EVOLUTION OF CELLULAR IOT

The installed base of Cellular IoT devices in the field today is still dominated by GPRS as a basic communication protocol. The GPRS (GSM) format has been available for more than 20 years and was still the major growth engine for C-IoT until 2016. CDMA and W-CDMA (UMTS and HSPA) devices also exist out in the market, but with lower numbers due to smaller regional deployments and less time on the market.

LTE has only been deployed for a few years so far, so the number of LTE devices is still ramping up. Multiple LTE variations are possible, ranging from high throughput (Cat 13 in uplink) to lower throughput (Cat-M1).

Many people would say that NB-IoT is also another category of LTE connectivity because it's designated as Cat-NB1 in 3GPP committees. We treat NB-IoT as a separate format because the basic RF waveform is different than LTE and does not rely on the same resource block allocations as the other levels of LTE.

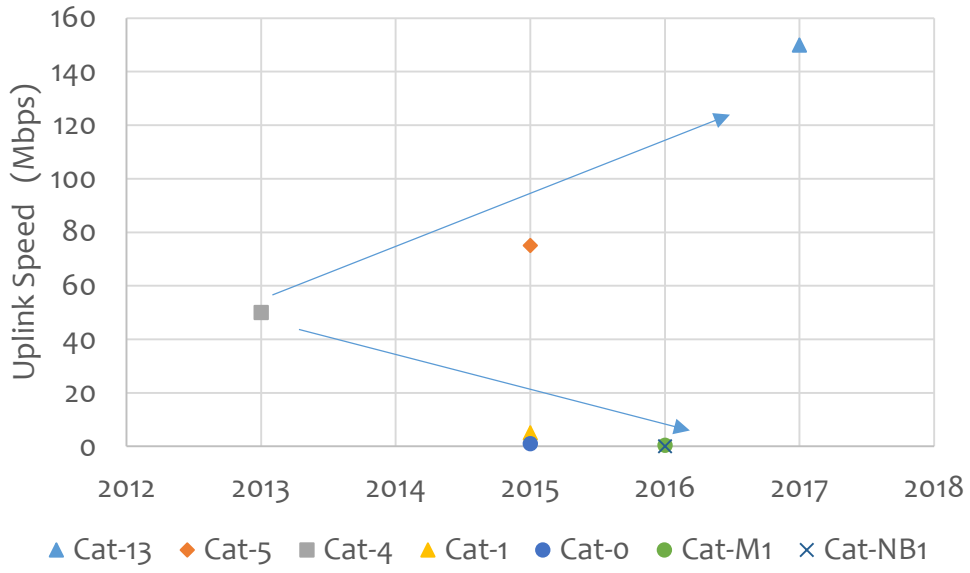


Figure 4 Divergence of LTE IoT formats over time

Source: Mobile Experts. Timing based on chipset availability

Notably, the LTE formats have evolved in two directions over the past several years. Since the first introduction of LTE modems with Cat-4 operation, the uplink has evolved in two directions at the same time: upward to Cat-13 operation in 2017, and downward to Cat-1, Cat-0, Cat-M1 (LTE-M), and Cat-NB1 (NB-IoT).

We charted these formats according to uplink speed, not downlink speed, because (unlike broadband apps where downlink is king) the uplink is the best metric for progress in IoT applications. In fact, the downlink has continued to progress upward with recent modem releases supporting up to 1.2 Gbps in LTE-Advanced, without upgrades to the uplink above 150 Mbps.

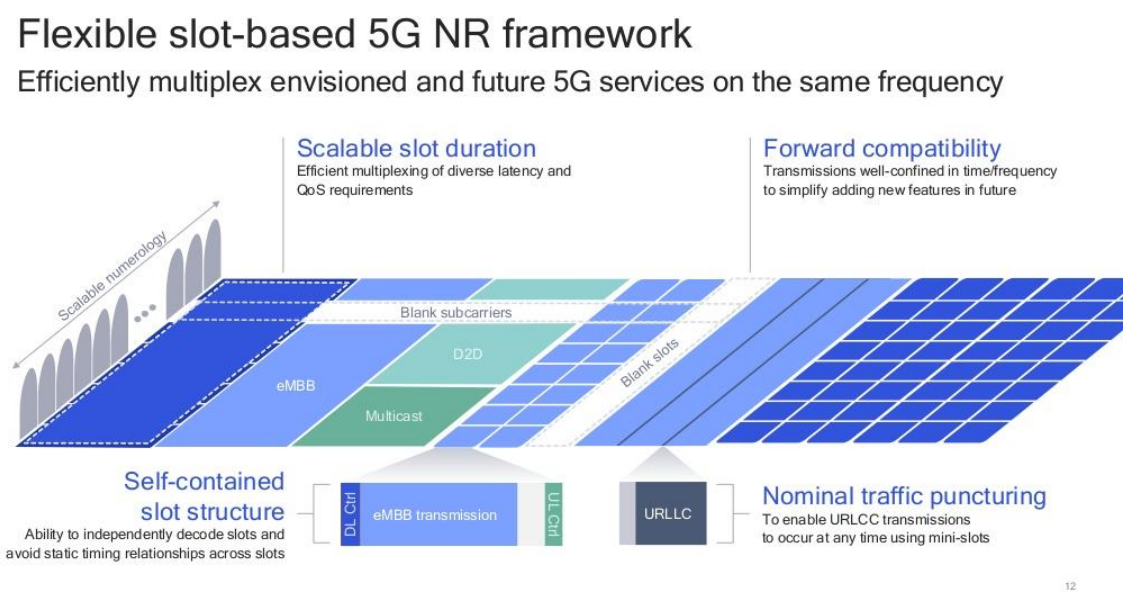
The question today remains: What is the next step in IoT? We currently see two trends, toward higher throughput and toward lower cost. At the same time, 3GPP committees are pursuing a third direction altogether: 5G is focused on low-latency, high-reliability IoT communications in Release 16, and later some people envision a focus on high device density. There are so many competing priorities that the Cellular IoT roadmap is very uncertain.

Our conclusion is that multiple IoT evolution paths should be evaluated individually:

- The trend toward higher throughput will continue, with Cat-20 devices leading to ever-higher throughput in low volume applications. The semiconductors will be re-used from mobile broadband devices such as smartphones, so the investment in this direction is certain.
- The trend toward lower cost will not be driven by continually changing the wireless standard. We expect NB-IoT to become a worldwide standard which will be adapted more gradually in the future, with incremental changes and backward compatibility in order to drive cost reduction through accumulation of volume.
- Low latency and high reliability are interesting features that enable a few applications that are not possible today. Over the longer term, 5G IoT focus in this area will pay off, but the growth will be disappointingly slow.
- High device density is a great discussion topic for conferences, but there's no real need for any focus in this area for many years. Any efforts to redesign the wireless format for high density will need to be carefully included in ongoing updates to NB-IoT without impacting backward compatibility.

5G NR

From the beginning, the RAN committees that developed 5G NR have been concerned with creating a frame structure that was flexible enough to handle broadband data and highly reliable, low-latency bursts.

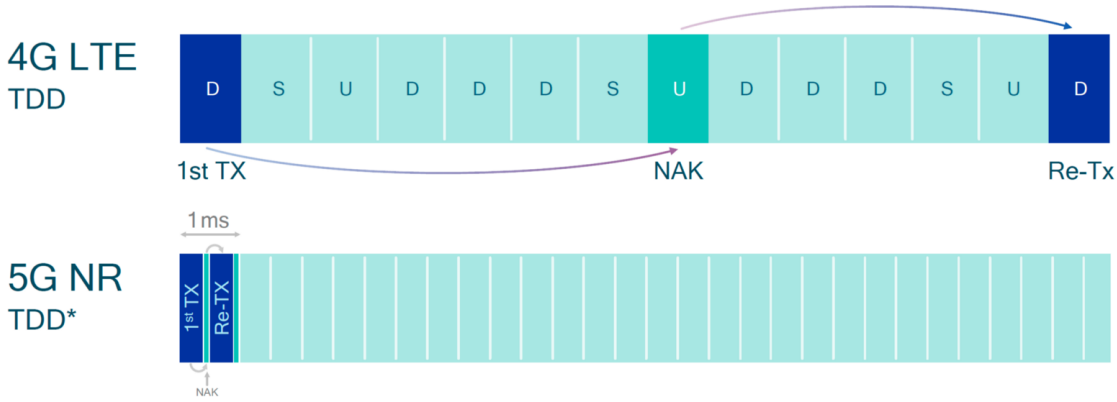


Source: Qualcomm

Figure 5. 5G NR frame structure and areas of flexibility

The 5G NR waveform has multiple improvements over LTE in terms of latency:

- The Transmission Time Interval (TTI) can be set to a much shorter time. Where LTE has a fixed TTI of 1 ms, in 5G the 'mini-slots' can be set to allow TTI in the range of 140 microseconds.
- The shorter slot lengths go along with higher 'numerology', which refers to the sub-channel spacing and basic setup of the OFDM access. The sub-channel spacing is typically locked into the hardware design, so changing the standard to allow for narrower sub-carrier spacings means that IoT can be quick while operating in a narrow band.
- The processing in 5G NR is quick, using only 1-2 symbols in the UE, and 7-14 symbols in the gNodeB. In this way, a message can be answered quickly.
- Grant-free uplink messages are possible with 5G NR, simplifying the control signals necessary to set up a link.
- Rapid Hybrid Automatic Repeat Requests (HARQ) are possible, greatly improving latency under marginal radio conditions.
- Puncturing is now available with 5G NR, so that other data traffic can be interrupted with mission-critical traffic without loss of continuity.



Source: Qualcomm

Figure 6. Low-latency HARQ will speed up 5G URLLC

WHICH TECHNOLOGIES WILL WIN?

Mobile Experts is tracking at least 75 different ways to connect IoT devices. To sort out the likely match between so many connectivity options and the market opportunities, o make sense of the market, Mobile Experts uses seven technical factors to differentiate market segments:

- Connection Range
- Data Speed
- Latency
- Reliability
- Functionality (One way, two way, OTA updates)
- Battery Life; and
- Cost (device cost, network cost, and service operating cost)

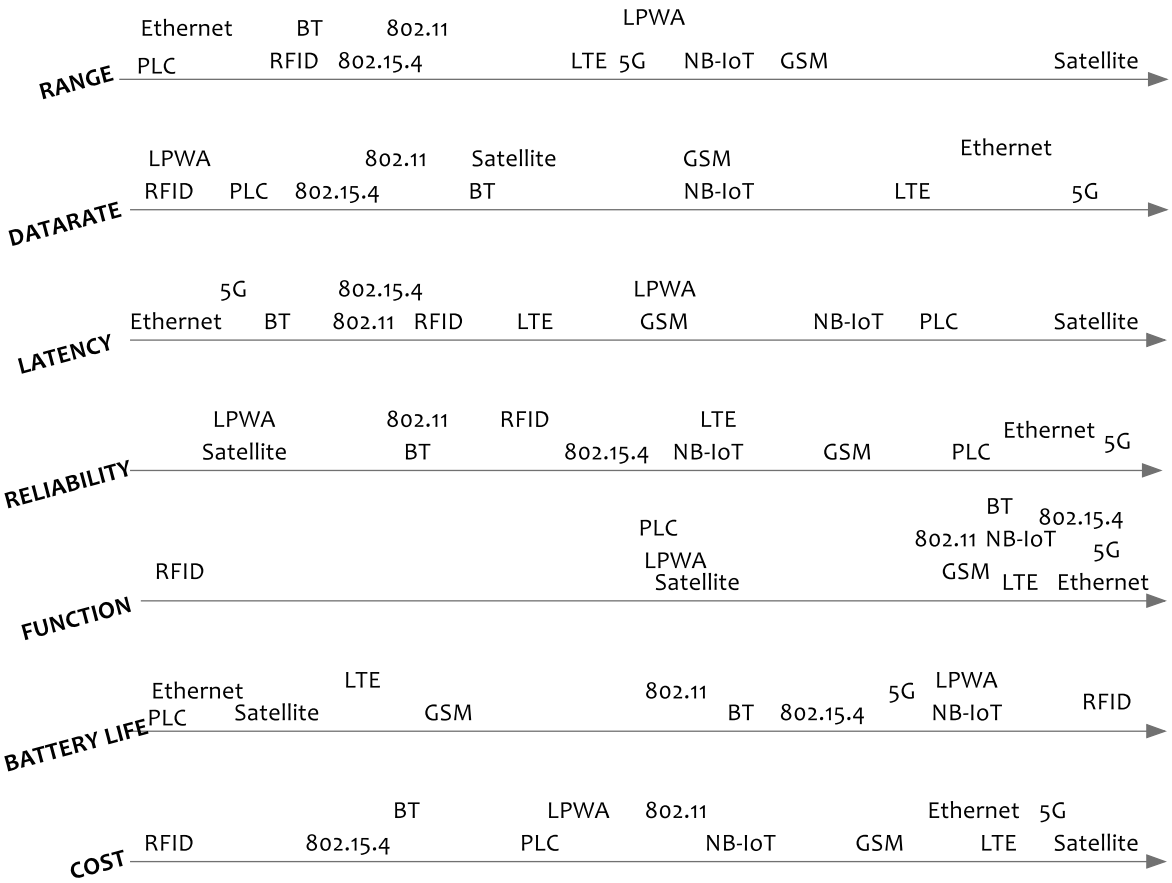


Figure 7 Seven Technical Factors that Differentiate IoT Applications

Source: Mobile Experts

Based on technical factors only, the broad variety of Cellular IoT standards can cover a broad range of market applications. GSM technology operates over long range. LTE handles high throughput. NB-IoT is coming to the market to offer long battery life. This report identifies the technical areas that match with each C-IoT format.

However, in addition to technical factors, business model factors must also be considered. NB-IoT may be a fairly low cost technology, but some customers are not willing to rely on a mobile operator and will choose LoRa in order to stay independent. Other premium applications will justify the higher cost of 5G IoT for URLLC. In short, the market will break into very distinct segments.

5 APPLICATIONS FOR C-IOT

Over the past four years, Mobile Experts has investigated eight different application areas so that we can fully understand the potential for growth in each IoT vertical market. Each of the detailed market studies can provide the details, but below we have composed a summary for each of the major application areas for Cellular IoT.

AGRICULTURE APPLICATIONS:

Farming has used automation for many years, with tractors and other farm equipment adopting GPS-based location awareness and automated driving to save labor costs and increase productivity. Big farming machines have plenty of electrical power, so connectivity using GSM or 3G technology was acceptable. Newer applications are now coming to market, taking the low power consumption of LTE-M and NB-IoT into account and allowing for small battery-based devices.

In agriculture, applications include:

- Soil moisture monitoring
- Vehicle and farm equipment automation
- Drone-based inspection of crops
- Drone-based "scarecrow" systems
- Livestock and equipment location tracking

The early applications had limited production volume due to the very expensive nature of highly automated trucks and harvesters. However, as we shift to small battery-fed devices the number of agricultural IoT devices will increase dramatically.

Figure 8 Automation of farm equipment

Source: Jed Owen

The major question in this application area is whether cellular IoT is the preferred mode of communication. Does the farm have adequate cellular coverage? If so, then most farmers will prefer to use an existing network—every operation from small landholders to huge industrial operations are likely to prefer an existing cellular network.

In areas without good cellular coverage, LoRa networks may emerge. We see investment in this direction by companies like Senet in the United States… the idea is that the cost of coverage per square kilometer is lower than an LTE-based network, and without licensed spectrum the deployment can be achieved much more quickly.

ASSET TRACKING APPLICATIONS:

Mobile Experts has examined six major areas of asset tracking, which occupy very different vertical markets but share many consistent themes in terms of tracking the location of devices. In particular, we focus on:

- Livestock (mainly cattle tracking): About 1.5 million cows are tracked today with collars or tags that use unlicensed LPWA or GSM/3G radios. We expect two technologies to dominate this segment in the long term: NB-IoT (where available) and LoRa (where no LTE-based options are possible)
- Healthcare applications are a very hot growth segment, given the need to monitor and track the shipment of drugs, some of which must be monitored for temperature.

Inside hospitals, Wi-Fi has been used for years to track expensive machines on wheels. Over time we expect almost all of these apps to move toward NB-IoT or LTE-M.

- Industrial operations need to track the location of various items. The items tracked can include products during manufacturing, trucks in a wide-ranging mining, logging, or energy operation, and other high-dollar items. In many cases these industrial operations are outdoors and require long-range technology for connectivity over a few miles… so NB-IoT technology may be ideal.
- Transportation: Asset tracking in the logistics area can range from tracking cargo ships to steel containers, to pallets or even individual boxes. Satellite-based devices are generally used for the ships, but as we move down to containers, pallets, and boxes the cost pressure is increasingly higher and low-cost devices are in demand. In these cases, global interoperability and connectivity are key features, so GSM still has a significant role today. Emerging standards like NB-IoT can reduce cost and make pallet or box tracking more practical.
- Retail operations generally use Bluetooth or Wi-Fi, with less use of cellular technology.
- Consumer devices have some extreme cost limitations, so unlicensed LPWA technology will be preferred in some cases (Sigfox has established some very low price points, so even in the likely case that Sigfox does not survive we expect the low pricing to remain). In other cases such as bicycle rentals, NB-IoT technology is expected to sweep across the market.

AUTOMOTIVE APPLICATIONS:

The automotive market is a premium case where mobility, wide range, and high throughput all come together. Auto manufacturers are not interested in deploying their own networks, but the dollar value on telematics information or insurance information can be high. Most cars sold over the next 10 years will include some level of LTE technology.

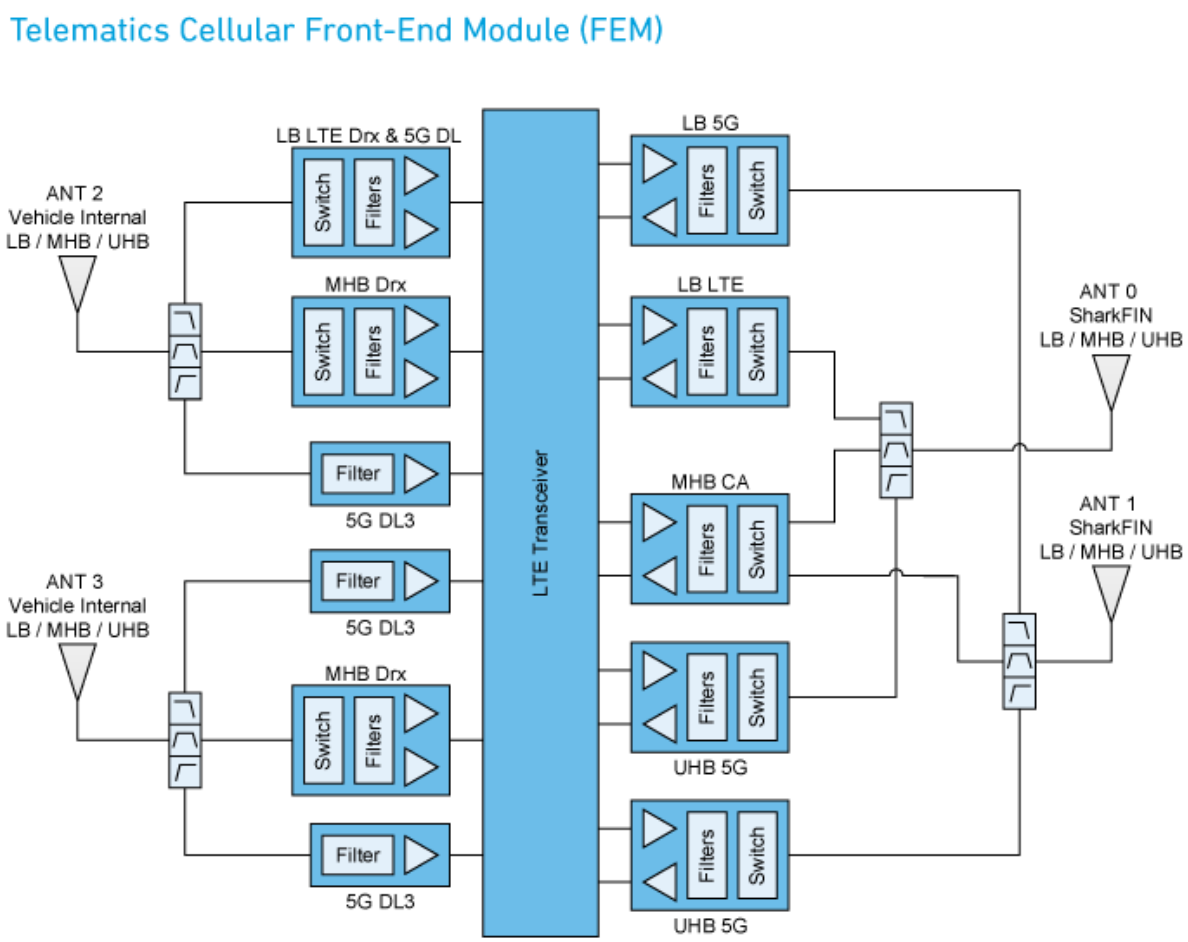


Figure 9 Schematic diagram for a typical automotive telematics module

Source: Qorvo

Key applications in the automotive sector include:

- Telematics: Reporting data on the car's operation can be useful to the OEM for maintenance and even prediction of failures to enhance reliability. Data throughput requirements can be fairly low in this case, although over-the-air firmware updates can involve huge amounts of data in some cases, requiring high-level LTE operation.
- Infotainment: Web entertainment in the car has become a luxury feature on the market that will not go away anytime soon. This feature can often cause an upgrade in requirements for the telematics modem to include high download speed. Currently automotive manufacturers are moving to Carrier Aggregation to support high data speeds at Cat-6 through Cat-18 levels in the downlink… and eventually this application will drive a move to 5G.
- Aftermarket fleet management devices are another strong element. A module that plugs into the OBD-II port in a car can report data back to a fleet manager as in a

rental car, or can report data to an insurance company in a business model known as Usage-Based Insurance. Power is not a major concern but reliable connectivity in wide coverage is key. LTE-M is emerging as a popular technology for this product area.

- Vehicle-to-Vehicle (V2V) communications will enhance safety by providing additional information to a car's array of sensors. The market is currently split on the use of 802.11p (DSRC), LTE, and 5G for this use case---no global resolution appears likely.

HEALTH-CARE APPLICATIONS:

Short-range wireless technologies have been used for patient monitoring (tethered to smartphones and local machines), but in the health care field, monitoring patients can be very tricky. Expecting the patient to navigate any technology steps (such as pairing a Bluetooth or Wi-Fi device to their phone) is not likely to succeed, so some healthcare device providers are considering a switch to NB-IoT technology. In this way, smart scales, smart pill bottles, and wearable patches could become more useful for professionals to monitor their patients.

Figure 10 Smart pill bottle using a 3G radio

Source: SMRxT

INDUSTRIAL APPLICATIONS:

Cellular IoT devices can save money in countless industrial applications, but we focus on the applications that require widespread coverage, that include mobility, or that have potential for premium pricing. Examples include:

- Electric Utilities: One of the most obvious applications to emerge recently involves the instrumentation of an electrical grid with sensors, to immediately detect a broken cable. In California, the 2017 and 2018 wildfires that killed hundreds of people (and cost tens of billions of dollars) would have been prevented by a system to shut down power within 400 ms of a cable breakage.
- Oil & Gas exploration, drilling, and transport requires a lot of simple information in remote locations. Technicians waste a lot of time driving out to a wellhead to check on whether a tank is full, or whether the pump is running smoothly. Where LTE coverage is available, these devices will generally use it.
- Large-scale operations such as an airport, a seaport, or a logging operation can use automated ground vehicles or can simply track items as they move around. The wide area of many operations leads to an advantage for LTE-M or NB-IoT.
- Manufacturing operations focus on minimizing downtime—work stoppage can cost millions of dollars for some manufacturing or process control operations. In a jet turbine assembly line or a giant brewery operation, sensors to monitor temperature, machine vibration, and many other variables can be an important part of predictive maintenance. In most cases this is handled with wires today, (Fieldbus or Ethernet), but flexible factories need high-throughput links without wires, and LTE can offer a more reliable alternative than Wi-Fi or other formats.
- Industrial-level transportation systems should be a strong growth area for LTE technology. GSM has been used for many years in train control and related communications… and in fact a separate band has been set aside for GSM-R in the 873-880 MHz band (uplink) and 918-925 MHz band (downlink). Advances in 3GPP will move the rail market into LTE-based communications to allow for higher throughput and lower latency.

SMART CITY APPLICATIONS:

Mobile Experts defines the Smart City area as a series of applications that the municipal government will pay for. The technology can be very similar to industrial devices or Asset Tracking devices, but the business model for a city can be different, with a lot more emphasis on the data analytics and other data-handling aspects. Smart city applications include:

- Smart street lighting is typically the first project that a city will try. As streetlights are upgraded to LEDs, the connectivity is often added as a "nice to have" feature.

- Traffic management solutions can be added to improve on positive control of traffic signals, using sensors and cameras to paint a picture of the overall traffic situation in a city.
- Smart waste management: This simple use case optimizes the routes and timing of garbage trucks, to ensure that "full" waste bins are emptied while "empty" bins are bypassed.
- Smart Parking systems: With sensors in the parking lot, drivers can be directed to an open space.
- Other applications include specialty systems such as pollen monitoring, gunshot location/detection, facial recognition, license plate identification, as well as basic utilities such as water/gas/electrical service.

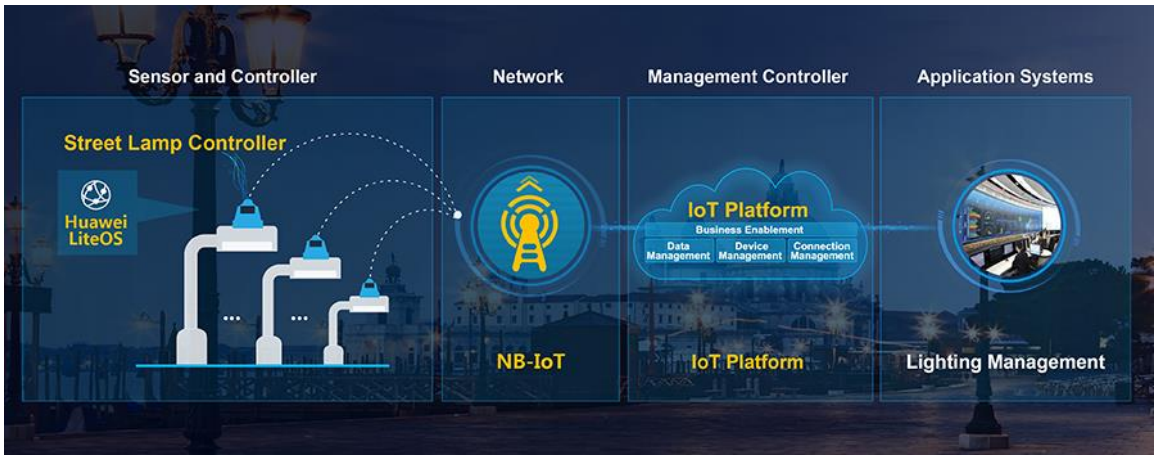


Figure 11 Streetlight Control System and Cloud Platform

Source: Huawei

SMART METER APPLICATIONS:

While smart meters can be viewed as an extension of the smart city, Mobile Experts tracks it as a separate category because many utilities are private companies, not government entities. This makes the decision-making process more proactive and ROI-based in the case of smart metering… and generally has resulted in faster growth for smart meters compared with smart city devices.

The smart meter application is pretty simple: Radios or power-line based IoT devices communicate usage information for electricity, water, gas, or heat to the utility. The original applications were developed as Automated Meter Reading (AMR) systems to allow for quicker meter-reading on a once-per-month drive-by basis. More recent systems have evolved as Automated Metering Infrastructure (AMI) which often reports usage data every 15 minutes. In addition to simply reporting usage, AMI can be used to enable and disable service, detect leaks or other problems, or even enable connectivity for the customer to see a real-time view of energy pricing, usage, or other information.

Figure 12 A Water Meter using NB-IoT

Source: Quectel

NB-IoT technology is expected to open up new areas in the Smart Meter market, as smaller utilities that have not chosen to deploy their own networks can now access reasonable solutions on an existing cellular network.

6 TECHNOLOGY COMPARISONS AND CHOICES

The roadmap of M2M or C-IoT technology is a long one, starting with early AMPS systems and CDPD… and leading to future ideas for 5G NR-based machine connectivity. It's important to distinguish between two eras in machine communications:

- M2M, (roughly 1990 to 2017) where machine communications simply took advantage of a network that was optimized for other purposes; and
- IoT (starting in 2017) where new cellular IoT formats are optimized for machines. LTE-M and NB-IoT belong to this category, where the air interface is scaled back to allow for longer battery lifetime.

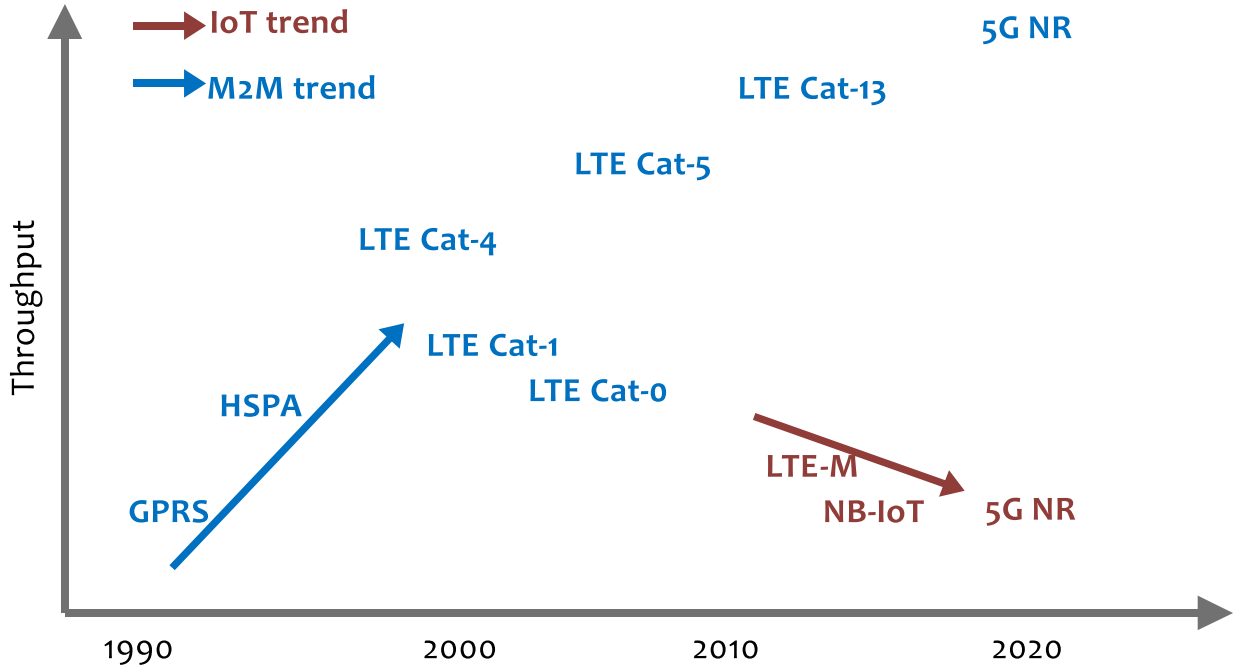


Figure 13 Illustrating the Difference between M2M and IoT

Source: Mobile Experts

Throughout the history of the M2M era, devices used cellular connectivity because it was the most convenient platform, not because it was the best technology for the purpose. Decisions about network connectivity or which device to use are made based on whatever is available. This trend continues with LTE Cat-5, Cat-13, and 5G NR devices that re-use smartphone devices for IoT applications.

However, as we go into the future, we expect the market dynamic to change. Starting in 2017, we saw dedicated Cellular IoT deployments with NB-IoT base stations shipped into China in large numbers as well as deployments in other key markets. Today, the air interface technology is tailored for small bursts of data over a longer range.

Standard	Channel Bandwidth	Downlink Throughput	Uplink Throughput	Latency	Comments
GPRS	200 kHz (divided into time slots)	9.6 kbps (one time slot)	9.6 kbps (one time slot)	500+ms	Large legacy installed base
HSPA	5 MHz	Up to 42 Mbps	Up to 22 Mbps	100+ ms	Multiple variations not covered in detail here
LTE Cat-4	20 MHz	150 Mbps	50 Mbps	10-50 ms	Basic symmetrical operation
LTE Cat-5/6	2x20 MHz	Cat-6, 300 Mbps	Cat-5, 50 Mbps	10-50 ms	
LTE Cat-13/12	3x20 MHz	Cat-12, 600 Mbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-13/16	4x20 MHz	Cat-16, 800 Mbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-13/18	5x20 MHz	Cat-18, 1.2 Gbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-1	20 MHz	10 Mbps	5 Mbps	10-50 ms	
LTE Cat-0	20 MHz	1 Mbps	1 Mbps	10-50 ms	Nobody uses this standard
LTE Cat-M1 (LTE-M)	1.08 MHz	300 kbps	375 kbps	10-50 ms	Release 13
LTE Cat-M2	5MHz	2.3 Mbps	1.5 Mbps	10-50 ms	Release 14
LTE Cat-NB1 (NB-IoT)	180 kHz	27 kbps	65 kbps	10-50 ms	Release 13
LTE Cat-NB2	180 kHz	87 kbps	60 kbps	10-50 ms	Release 14 variation
5G NR	TBD	TBD	TBD	1 msec targeted	Standards expected in Release 16, late 2019 to early 2020.

Figure 14 Distinctions between 14 different Cellular IoT air interface standards

Source: Mobile Experts

ENERGY PER KB OF DATA:

The efficiency of the radio link is improving as we optimize technology for long-life batteries. A typical GPRS modem consumes 0.8 mA of current (3.5V) or about 2.8 mW of power in idle mode, and up to 960 mW in active transmit mode….to transfer 9.6 kbps of data. HSPA and LTE evolution took the power consumption in the wrong direction, increasing the current consumption for the device and thus shortening the battery lifetime.

LTE-M and NB-IoT allow for the IoT devices to go to sleep using the Release 13 Power Saving Mode (PSM), thus dramatically reducing the energy consumption from "idle" mode to "sleep" mode. In addition, the optimization of the air interface for small packets allows for the active current draw to be far lower.

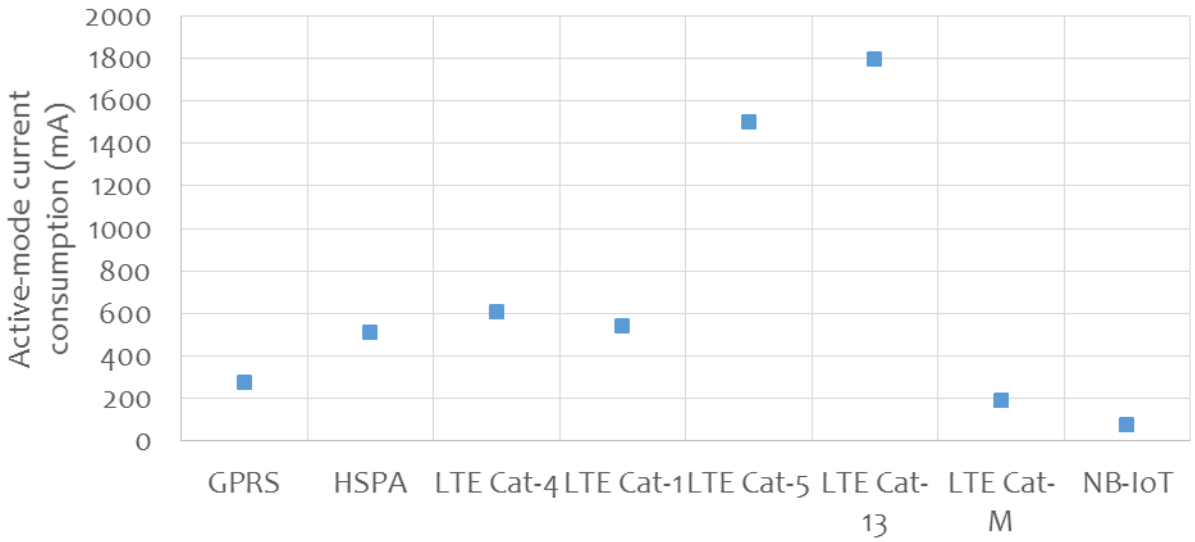


Figure 15 Current Consumption for various M2M and C-IoT formats

Source: Mobile Experts

The current consumption is lower for LTE-M and NB-IoT, but the data throughput is also lower than other cellular standards. So are the new formats really more energy efficient? The short answer is yes. Because PSM allows the device to drop from "idle" mode to a much more dormant state, for most of the time the current consumption drops from about 1 mA to a few microamps.

The true power savings for LTE-M or NB-IoT will depend on the application, and how often the device drops into a deep sleep state. For a typical application (with 10 kB sent every 15 minutes), the power savings of PSM is significant.

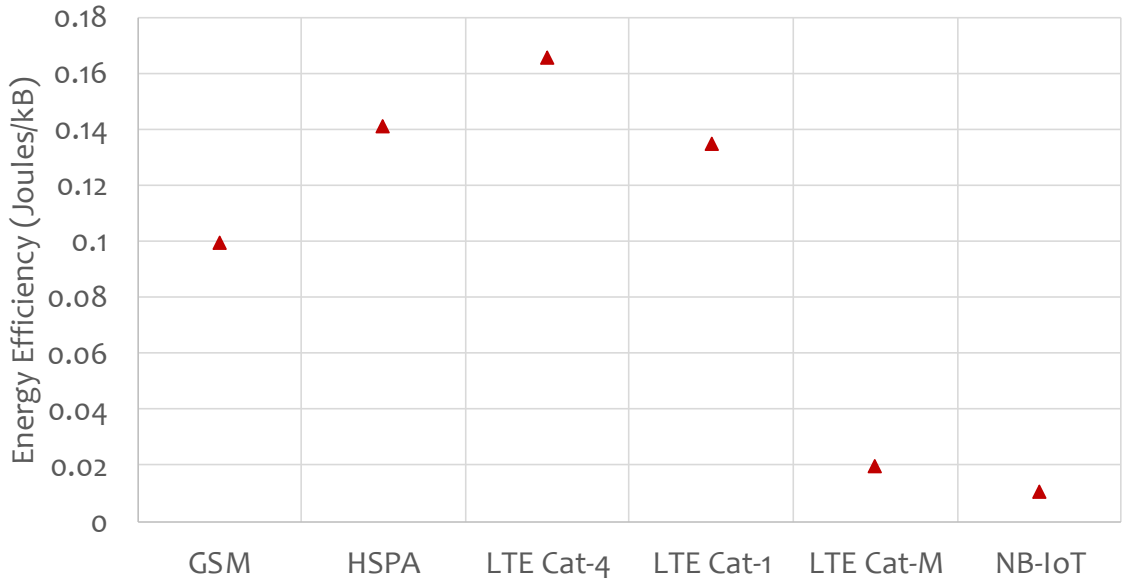


Figure 16 Energy Efficiency (Joules/kB) for various M2M and C-IoT formats, 15 minute intervals

Source: Mobile Experts

However, in a case where data is sent more continuously, PSM has less impact and Cat-M looks very similar to Cat-1. In the below chart, the IoT device spends 10 seconds in either "idle" or PSM mode, then sends its 10 kB packet.

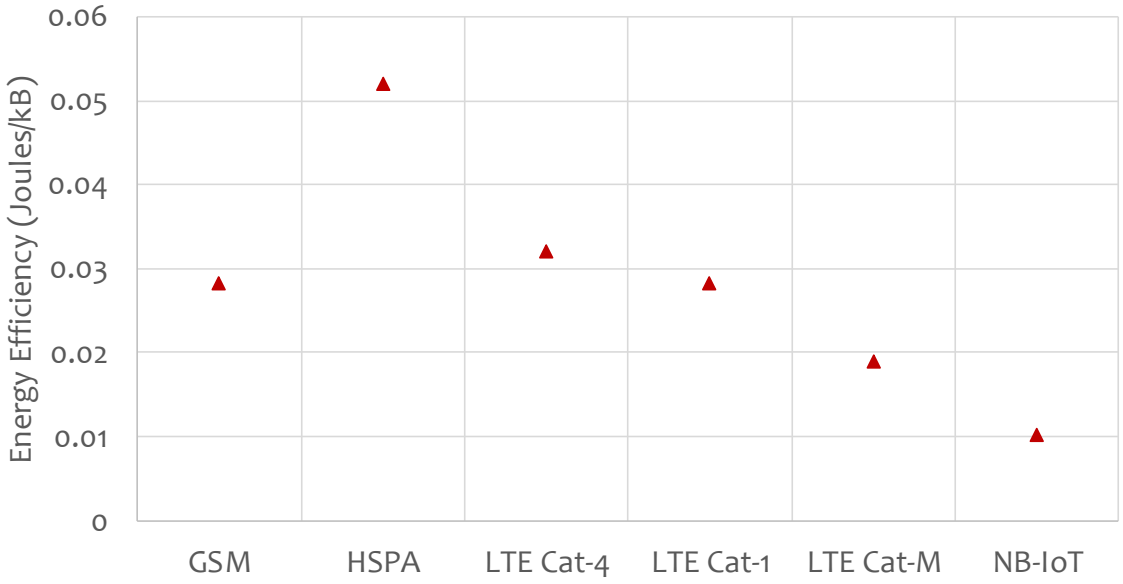


Figure 17 Energy Efficiency (Joules/kB) for various M2M and C-IoT formats, 10 second intervals

Source: Mobile Experts

COST COMPARISONS:

In the past, the business model for mobile operators has relied on cost reductions in "cost per GB" to offer large buckets of data for a fixed price. In this way, a new standard can help the business model through reductions in cost of delivering each GB. It's critical, because the operators sell each GB of data to the public for a price level that is only about 2x their raw cost (not including costs for marketing, overhead, etc.).

With the IoT market, however, the cost per GB of data seems to be much less meaningful, because the revenue associated with each GB is 100x to 1000x higher than the cost of delivery. Instead, the key cost factors to focus on are the network costs to support an IoT standard, and the costs of the devices themselves.

In general, the network cost depends on the legacy radio equipment in the field. Most operators in the USA and Europe have "modernized" radios in the 800-2300 MHz bands, which allow for a software upgrade to support LTE-M or NB-IoT channels. Some other operators, notably in China, did not have this level of flexibility in their old GSM base stations, and they were forced to buy new NB-IoT radio equipment.

COST PER SQUARE KILOMETER OF COVERAGE:

The cost of the network is a difficult concept to quantify, because each operator accounts for the IoT network differently. To make a valid comparison, we amortize the total cost of ownership of mobile networks, according to data usage.

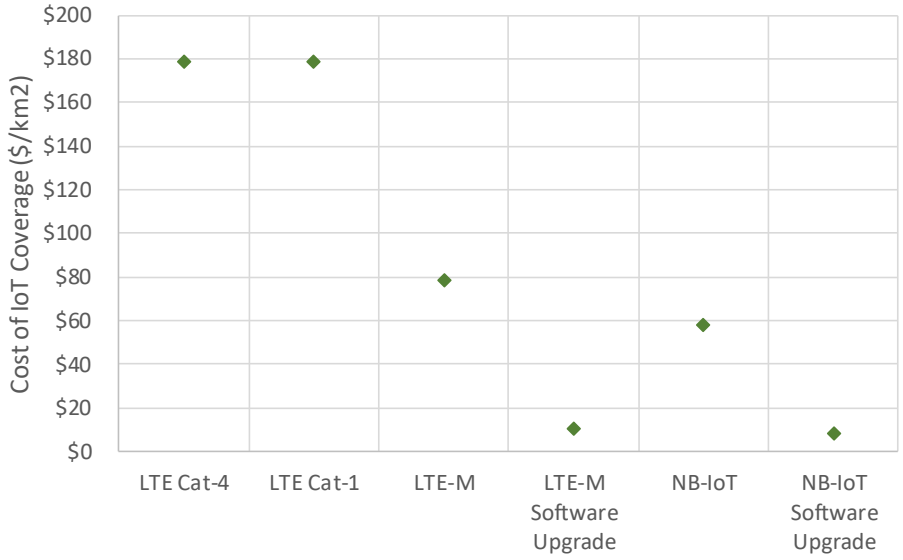


Figure 18 Cost per Square Kilometer ($/km2) for various M2M and C-IoT formats

Source: Mobile Experts. Total cost of ownership per square kilometer shown.

Looking at the apples-to-apples comparison of a new Cat-4 network vs. a new LTE-M network, for each square kilometer of coverage the Cat-4 network is roughly twice as expensive. Compared with a new NB-IoT network the cost difference is roughly triple.

The cost comparison is even more compelling when looking at true costs. Because LTE-M or NB-IoT are normally deployed as a software upgrade to an existing LTE site, the cost is much lower in reality than a new greenfield network. For a deployment of NB-IoT, the real-world TCO is likely to be only about $8 for every square kilometer.

THE IMPACT OF LATENCY

Media reports have made a big deal out of the importance of latency below 1 millisecond. But in the market, the need for this level of latency is much less proven. Automotive OEMs such as GM, Honda, Volkswagen, Daimler, and Toyota have all advised us that 10-20 ms latency is ok for their vehicle-to-vehicle systems, and that their automation does not depend on lower latencies.

Having said that, we believe that applications will emerge that drive a new class of IoT devices in low-latency applications. Today, there are still some missing pieces: Mobile

edge computing must be in place, and the operators remain unconvinced of the business model for placing computing resources at the radio site.

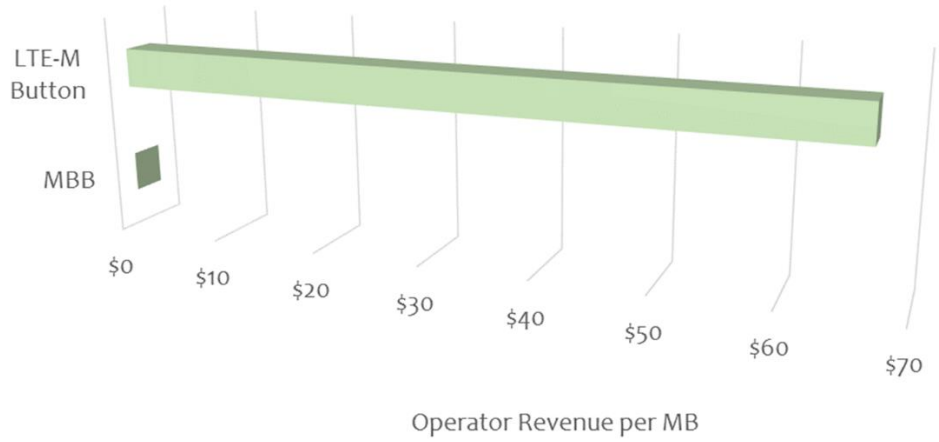


Figure 19 Revenue per MB for LTE-M

Source: Mobile Experts

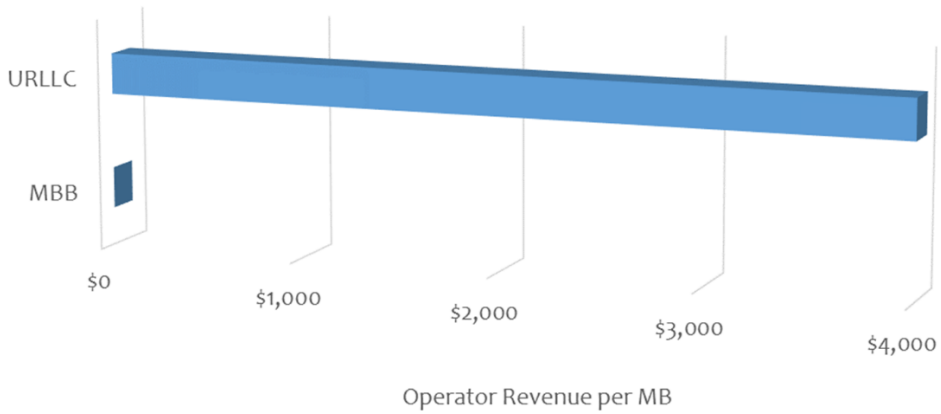


Figure 20 Revenue per MB for 5G URLLC IoT

Source: Mobile Experts

WHICH CELLULAR IOT STANDARDS WILL BE USED?:

Not all of the 14+ variations of Cellular IoT are recommended for new devices in the future. Here are some simplified conclusions:

- GPRS has a huge installed base but the longevity of the network is likely to be short;

- HSPA consumes a lot of power and networks are likely to be shut down soon;
- LTE Cat 4 through Cat 20 variations are useful for high-throughput apps but only where power efficiency is not critical.
- LTE Cat 1 is starting to die because it's fairly new and Cat-M and NB-IoT will take over the low bandwidth applications;
- LTE Cat-0 has already died from lack of benefit compared with Cat-1;
- LTE Cat-M is actually cheaper than NB-IoT for each kB of data and has higher throughput for voice apps and other uses, so Cat-M will be useful for higher data usage.
- NB-IoT has the lowest power consumption and lowest cost for coverage. NB-IoT devices are already more than 30% cheaper than Cat-M devices due to Chinese chipset subsidies. This will be the biggest winner in terms of volume deployment, and it will evolve with -NB2 and ongoing evolution;
- 5G NR has the advantage of low latency and the possibility of higher reliability with "puncturing". Its ideal use may be for on-premises enterprise networks, but over the long term wide area networks will be made available.

7 OUTLOOK FOR CELLULAR IOT

As we predicted last year, the market has started to accelerate from the sleepy growth of the M2M era. NB-IoT shipments in China have added nicely to the baseline of cellular IoT shipments, and we expect both NB-IoT and LTE-M to drive a higher growth rate for the next five years.

Note that we have updated our IoT forecasts to show a ten-year timeline instead of our usual five-year forecast horizon. Because of the long time scales involved with industrial markets, we feel that it's important to consider longer term product planning.

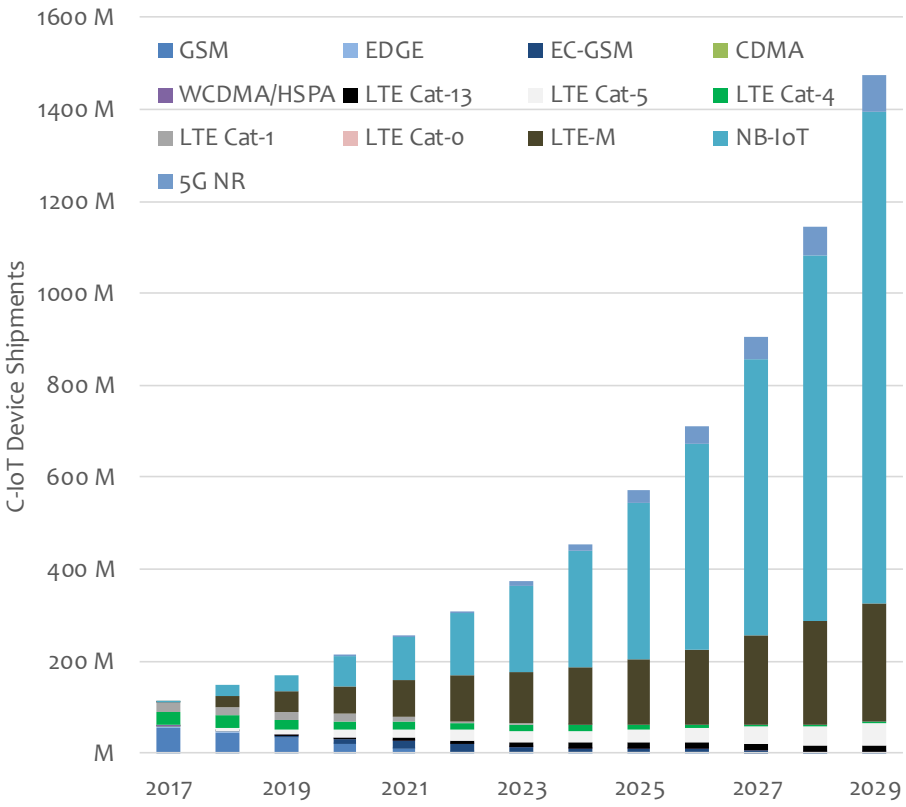


Chart 2: Cellular IoT Device Shipments, by technology, 2017-2029

Source: Mobile Experts

IoT Breakdown by Standards:

The biggest category for IoT devices remains in the "short-range wireless" area, with Bluetooth and similar devices representing about half of the shipments on the market. Cellular IoT is growing relative to wired devices, satellite-based devices, and unlicensed LPWA.

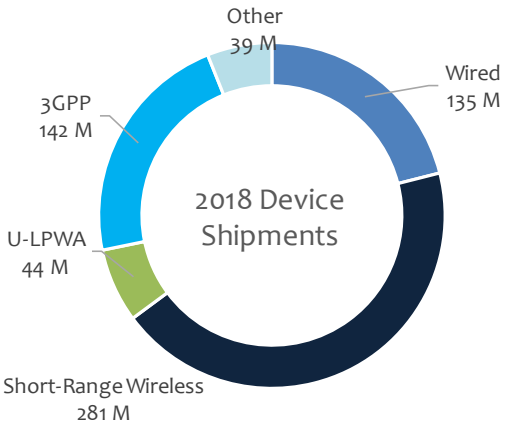


Chart 3: Breakdown of IoT Shipments, C-IoT vs Other Formats, 2018

Source: Mobile Experts

Over the next five years, Cellular IoT will get stronger as a share of the market. The outdoor and enterprise business models are expected to grow faster than the "smart home" and similar short-range IoT applications. This won't be a dramatic change but we will see increasing focus on higher power transmissions and 3GPP-based wireless formats.

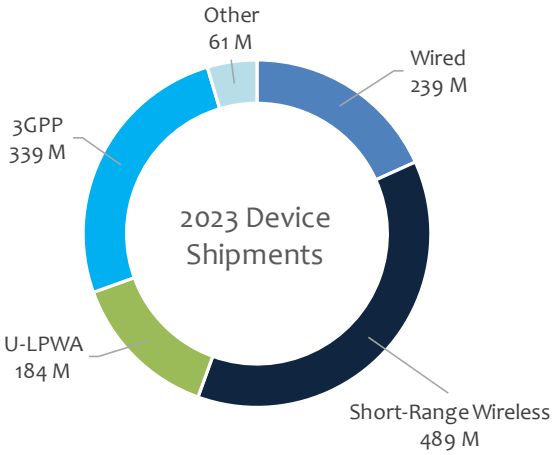


Chart 4: Comparison of Short-Range Wireless, LPWA, and Cellular IoT Shipments, 2023

Source: Mobile Experts

LTE-M AND NB-IOT VS. GSM, CDMA, EC-GSM, HSPA:

Over the long term, we expect some simplification in the C-IoT market… but for now, we are dealing with fragmentation. An incredible number of different formats are still used, ranging from GSM and CDMA through Cat-M and NB-IoT.

Starting in 2018, we see significant shipments for NB-IoT and LTE-M, and we can start to draw some trend lines that indicate much higher growth for these battery-optimized formats.

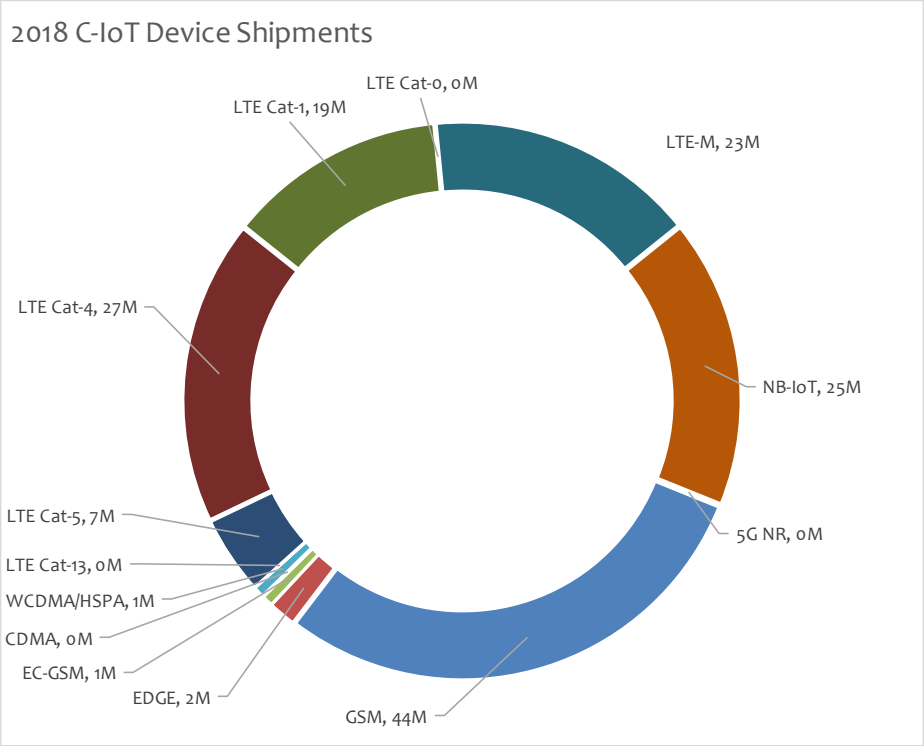


Chart 5: Technology Breakdown of Cellular IoT Shipments, 2018

Source: Mobile Experts

By 2023, we will see a dramatic shift in shipments toward NB-IoT and Cat-M, but some formats such as GSM and HSPA will still be shipping in nonzero quantities.

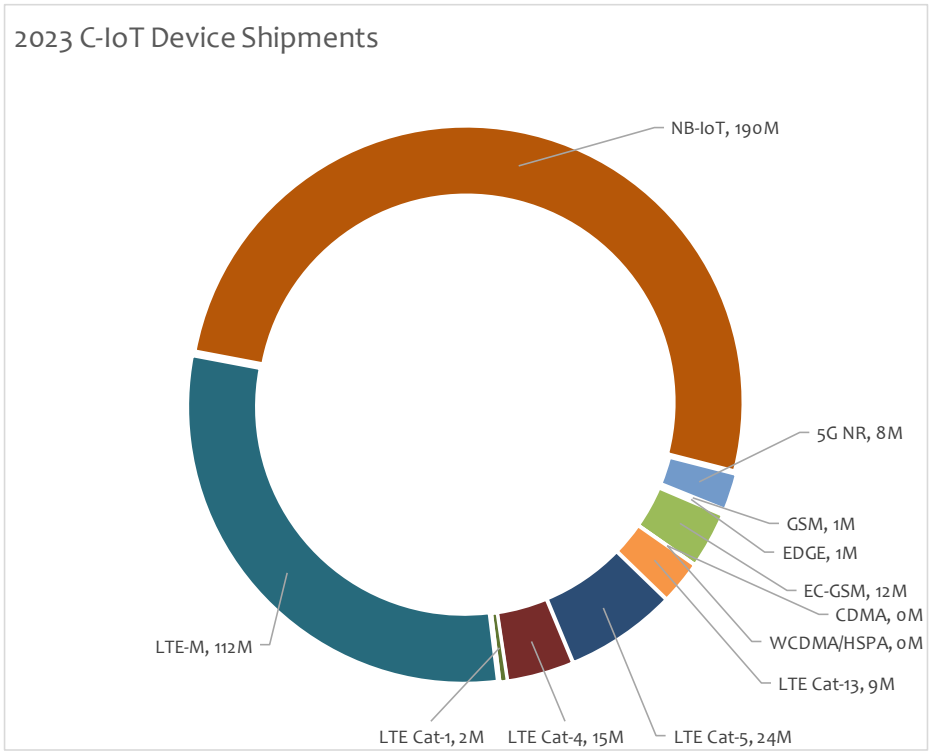


Chart 6: Technology Breakdown of Cellular IoT Shipments, 2023

Source: Mobile Experts

Ten years from now, we expect CDMA, HSPA, GSM, and other legacy formats to be completely gone (in some cases replaced by, for example, EC-GSM). We list the largest quantity in 2029 for NB-IoT, but in fact we expect the majority of shipments to be attributed to the successors of NB-IoT, such as Cat-NB2, Cat-NB3, etc. In other words, we expect compatible versions of NB-IoT to carry on with the growth of the market over the longer term.

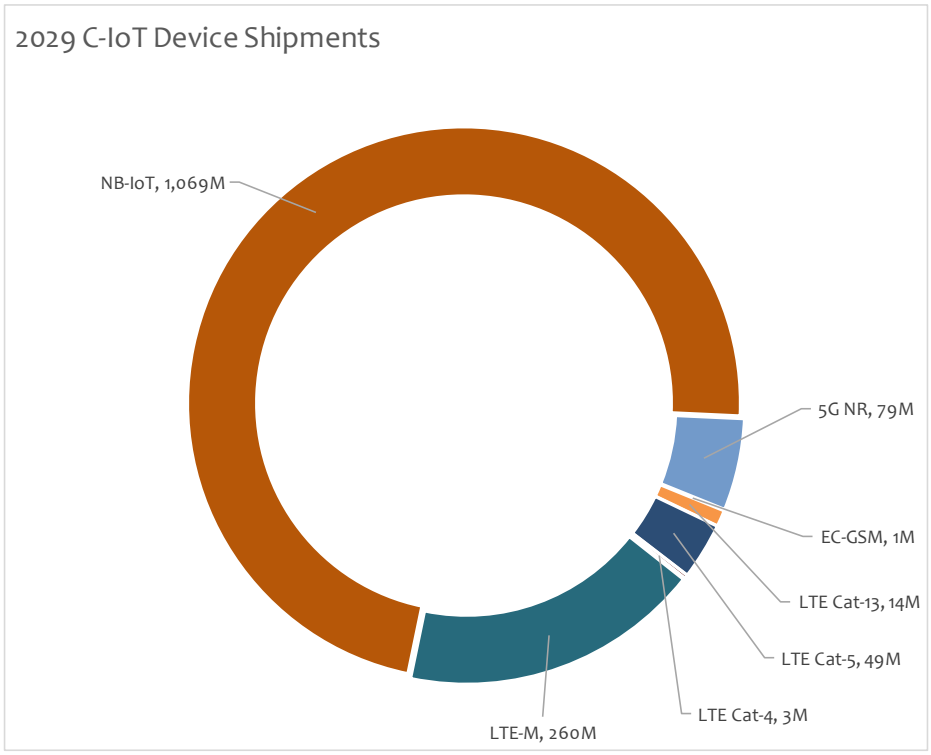


Chart 7: Technology Breakdown of Cellular IoT Shipments, 2029

Source: Mobile Experts

Several applications will account for major growth in C-IoT. This overall market growth is a pretty safe bet, because the risk is spread across markets ranging from automotive to healthcare, industrial, and Asset Tracking.

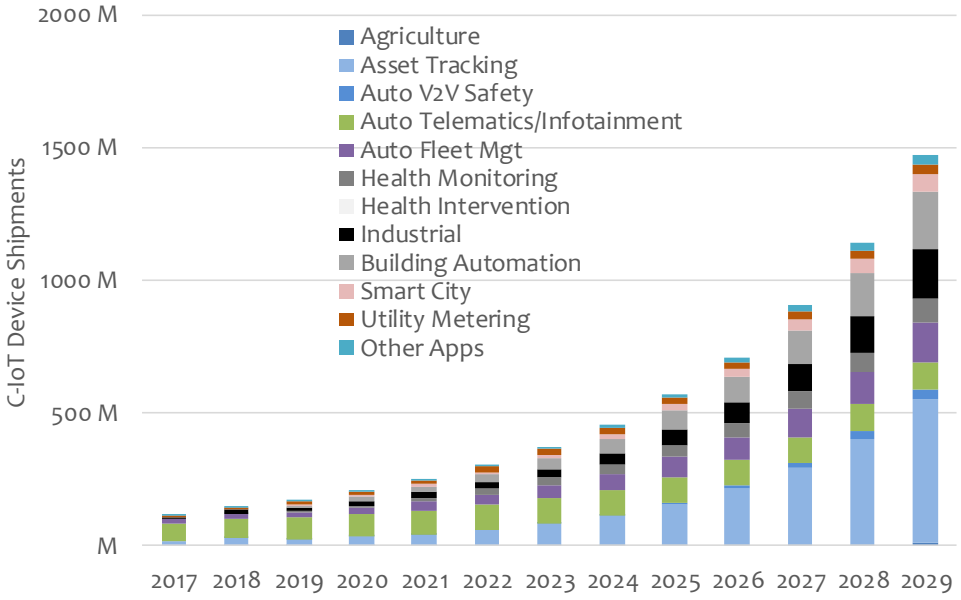


Chart 8: Cellular IoT Device Shipments, by application, 2017-2029

Source: Mobile Experts

The installed base of C-IoT devices has reached a level of about 620 million units. Most units remain in use for at least 10 years, so this number keeps growing steadily. Because the enterprise markets served are so large, and can absorb strong growth over a long time, by 2029, we expect the total Cellular IoT installed base to reach about 9 billion units.

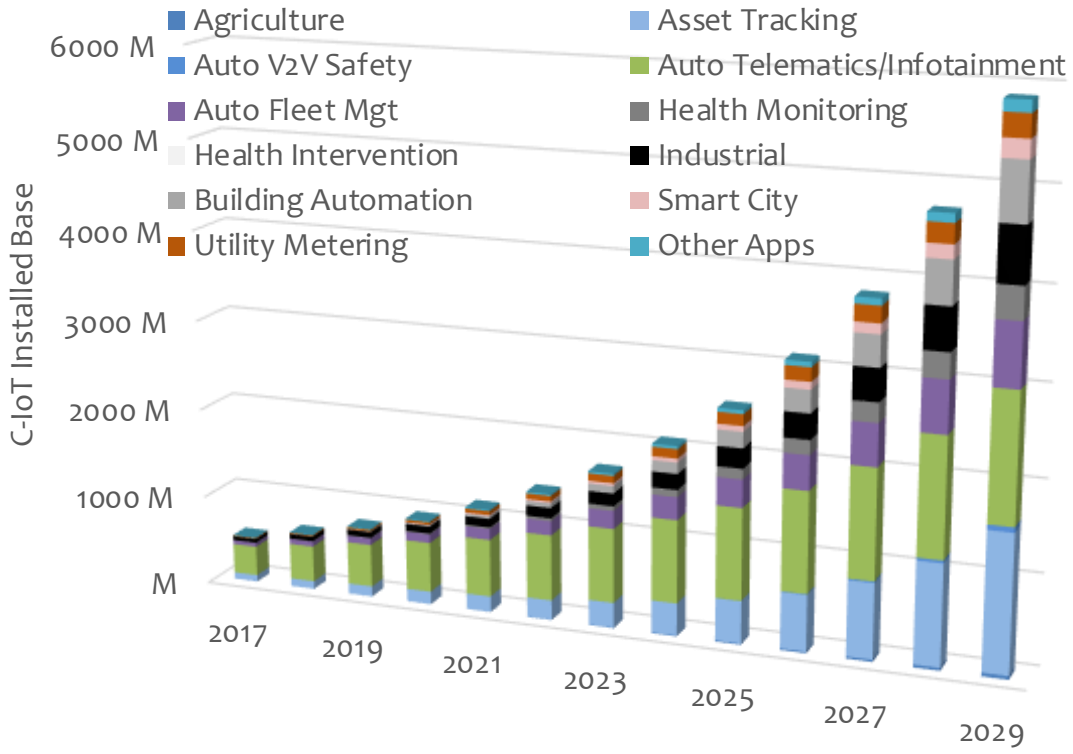


Chart 9: Cellular IoT Installed Base, by application, 2017-2029

Source: Mobile Experts

SERVICE REVENUE FORECAST

In China, we have thankfully seen some rationalization of the service revenue per NB-IoT device, which gives us more confidence in the long term revenue opportunity for operators. In cost-competitive markets such as China, we currently see levels of $3 per device per year (this is actually an increase from the $2.50 per year in early 2018). New applications can also demand premium pricing, as high as hundreds of dollars per month. Overall, the large number of cars and trucks tracked at premium prices makes the automotive market one of the most attractive sectors.

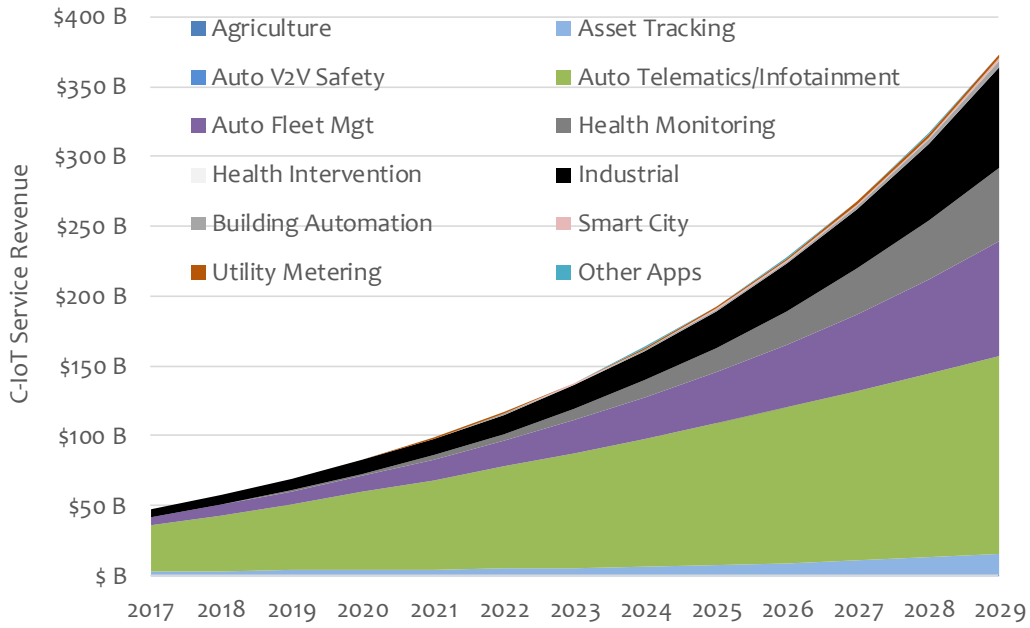


Chart 10: Cellular IoT Service Revenue, by application, 2017-2029

Source: Mobile Experts

DEVICE REVENUE

The device (including the C-IoT module or semiconductor components, plus sensors, memory, battery, antenna, enclosure) will vary widely between different applications. Device revenue and average prices will also differ widely between various use cases. Truly mobile applications will demand high-end LTE modules, and industrial devices will require ruggedization that simpler C-IoT modules (such as asset tracking devices) are not likely to use. In this way, even a cheap NB-IoT chipset can drive high device cost in a ruggedized application so the device revenue does not correlate well with the connection format.

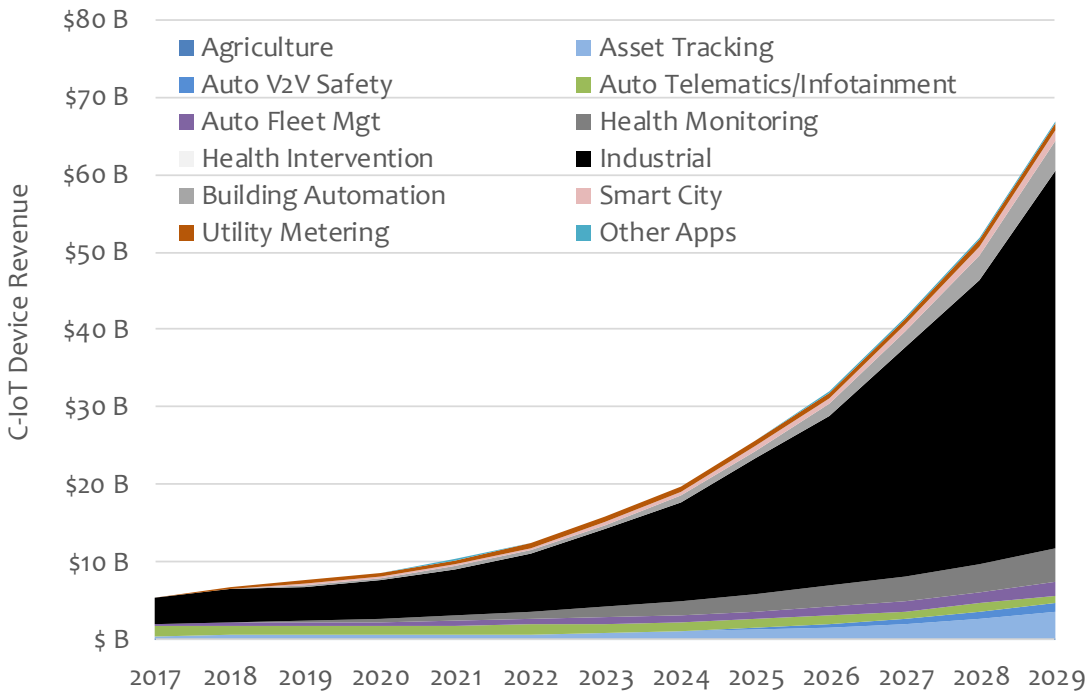


Chart 11: Cellular IoT Device Revenue, by application, 2017-2029

Source: Mobile Experts

CELLULAR IOT MODULE REVENUE

Cellular IoT modules that integrate the modem and RF components at a minimum will represent the majority of the market going forward. Companies that build an industrial sensor, or a drone, or a car are not interested in RF design work. In fact they often have very little RF expertise to be successful in that kind of integration, so purchase of C-IoT modules will remain the primary business model.

GNSS is often integrated with the C-IoT module, but in our analysis we have excluded the GNSS function in terms of its impact on pricing and revenue. We have also excluded modules that are used for PC and hotspot applications (for coverage of the entire market including handsets, PCs, tablets, and IoT, refer to the Mobile Experts research on RF Front Ends for Mobile Devices)

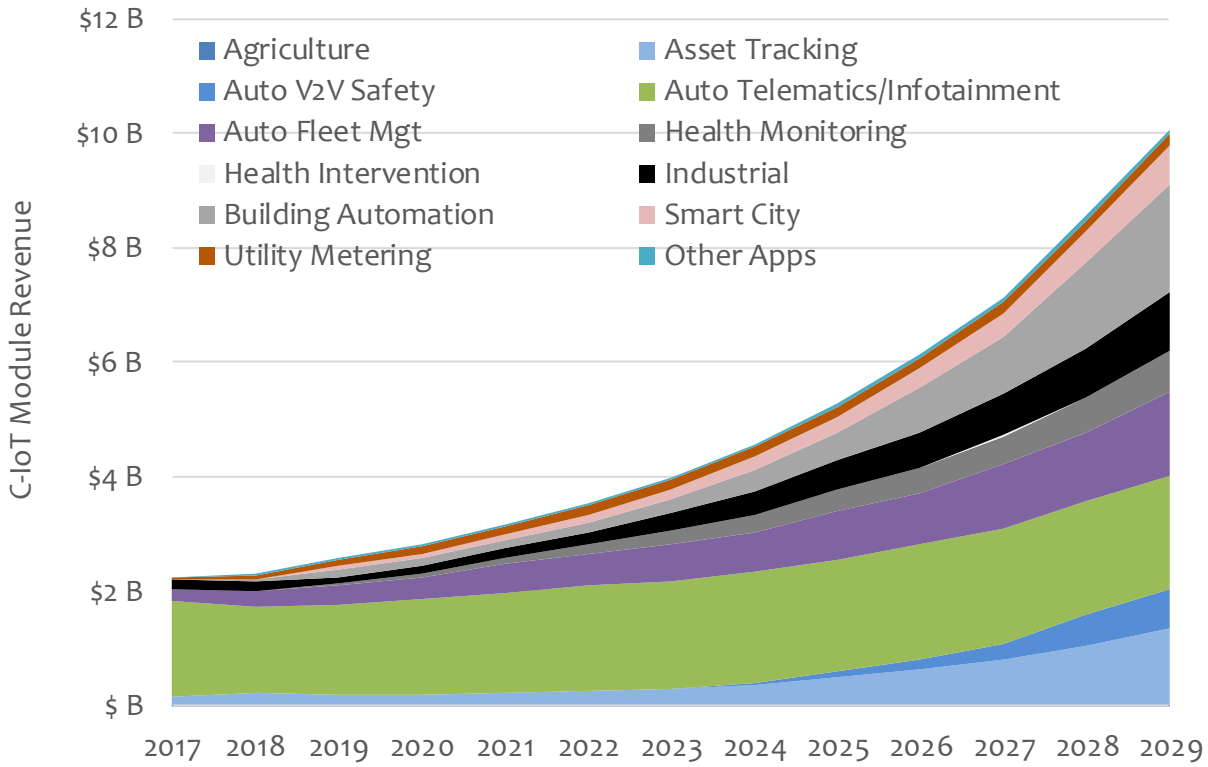


Chart 12: Cellular IoT Module Revenue, by application, 2017-2029

Source: Mobile Experts

As the technology shifts to LTE-M and NB-IoT, we expect increasing use of modules with high level economy of scale through key suppliers. Doing it yourself with discrete semiconductors will only be for big companies with huge volume.

The 5G IoT market carries a lot of unknowns. Currently we assume a premium modem and multi-band RF content, resulting in a high semiconductor cost for 5G IoT modules. As the 5G market develops, we will then see how strong the chip revenue can be. Excluding 5G IoT, the strongest revenue will come from NB-IoT (high volume, low cost) and LTE-M (lower volume, mid cost). Other LTE modules (Cat-5 through Cat-20) will likely lead to some form of 5G connectivity over time, but for the purposes of this chart we have left the automotive market in the LTE Cat-4 through Cat-20 categories to illustrate the ongoing revenue potential in that segment.

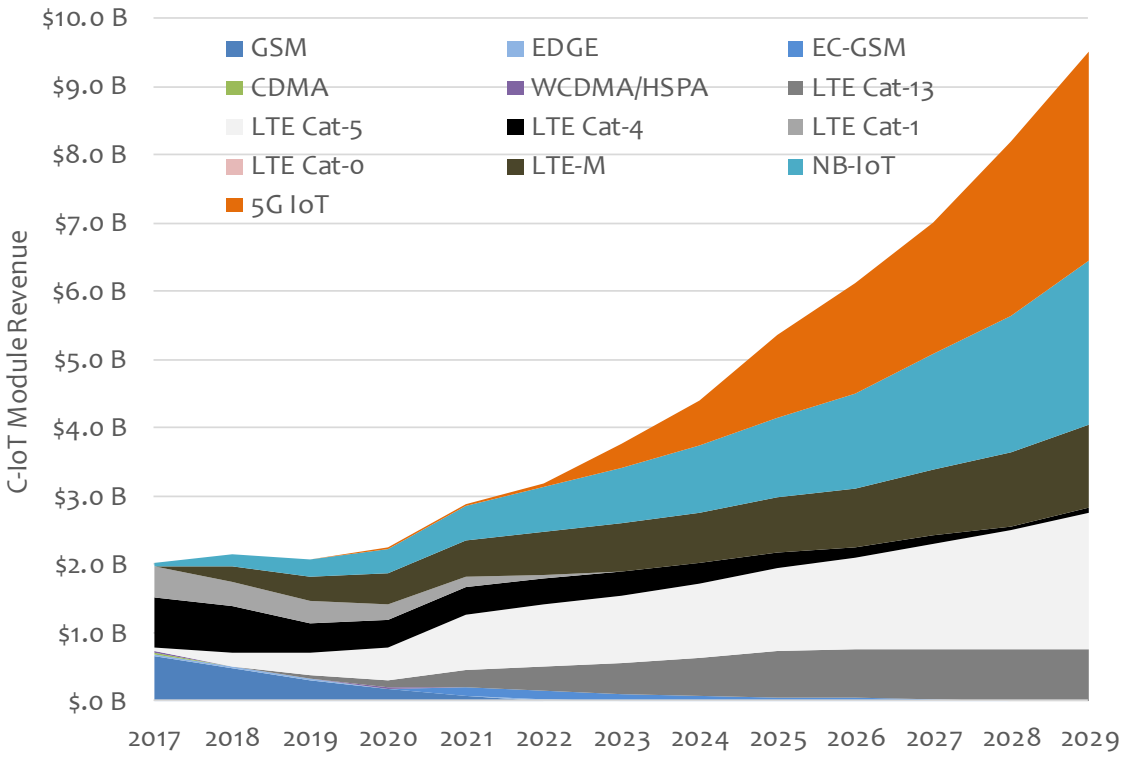


Chart 13: Cellular IoT Module Revenue, by technology standard, 2017-2029

Source: Mobile Experts

Sierra Wireless is the #1 supplier with $720 million of module revenue, and Sierra is pushing to strengthen their position with added value in software platforms and services on top of the devices. U-Blox is strong in the European market with 60% of revenue in industrial areas and 30% in automotive. U-blox leads the market for positioning modules as well (these are excluded from our revenue and share estimates). Telit is divesting their automotive product line, but during 2018 the automotive revenue still counts, and their total module revenue grew to about $350M. Gemalto has solid revenue share with a strong European presence (as the former Siemens M2M business) related to automotive, healthcare, asset tracking, and smart meter markets.

Quectel has grown very quickly, with an early entry into NB-IoT and strategic use of both Qualcomm and HiSilicon chipsets. In 2018, Quectel rose to the top tier with more than $200M in module revenue. SIMCom was sold to Shenzhen Sunsea for a disappointingly low $78M, roughly the same as their annual module sales. Combining SIMCom with Longsung, Sunsea reached revenue of roughly $80-90M in 2018. WNC is small but has a strong position in the Americas and some Asian countries. Several other Chinese and Taiwanese vendors are emerging to use HiSilicon chips with Huawei software and cloud platforms, so the NB-IoT module market will be a low-margin business in China.

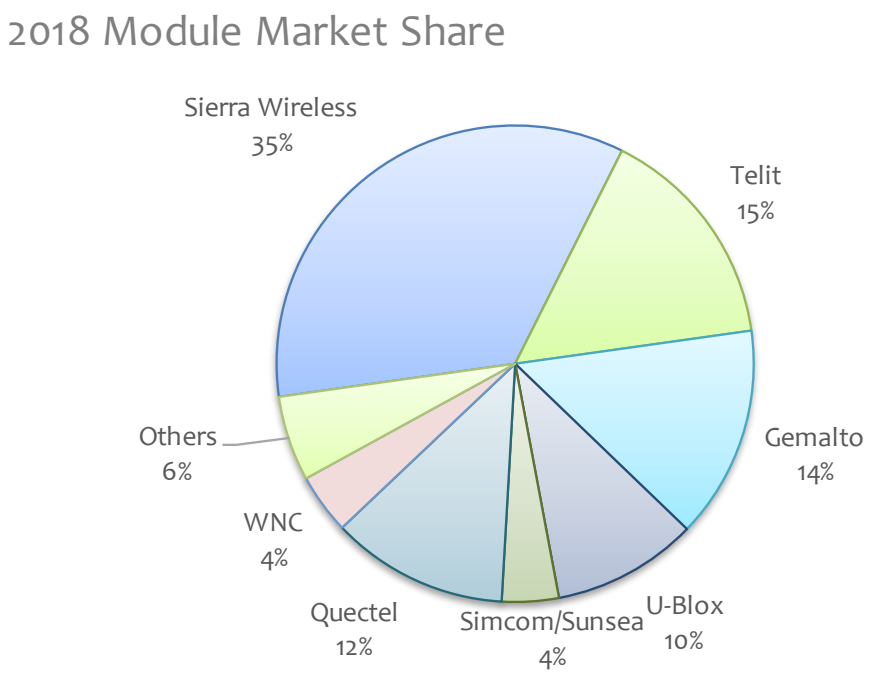


Chart 14: Cellular IoT Module Market Shares, 2018

Source: Mobile Experts. Note: Not including GNSS, or PC/hotspot modules….IoT only

Semiconductor subsidies in China are skewing the market for NB-IoT semiconductors, but the overall market for GSM, LTE, and other C-IoT chipsets continues to grow briskly. Overall, shipments are growing nicely but the strong price erosion associated with LTE-M and NB-IoT will flatten the revenue picture.

One counter-trend is the rise of multi-band, multi-mode modules with Carrier Aggregation and MIMO features. Especially in the automotive and industrial markets, we expect to see a rise in the dollar content associated with each module.

In total, we expect pricing to drop quickly for many IoT semiconductors, which means that market growth will not result in such high revenue growth for chip vendors in the 2018-2020 time period. However, when NB-IoT volume grows to be significant we expect a steeper revenue growth curve for C-IoT semiconductors.

Note that 5G IoT will not be significant in the next four years, but we expect the premium applications to drive strong dollar content for multi-band 5G IoT modules with MIMO and Carrier Aggregation, as well as expensive 5G modems.

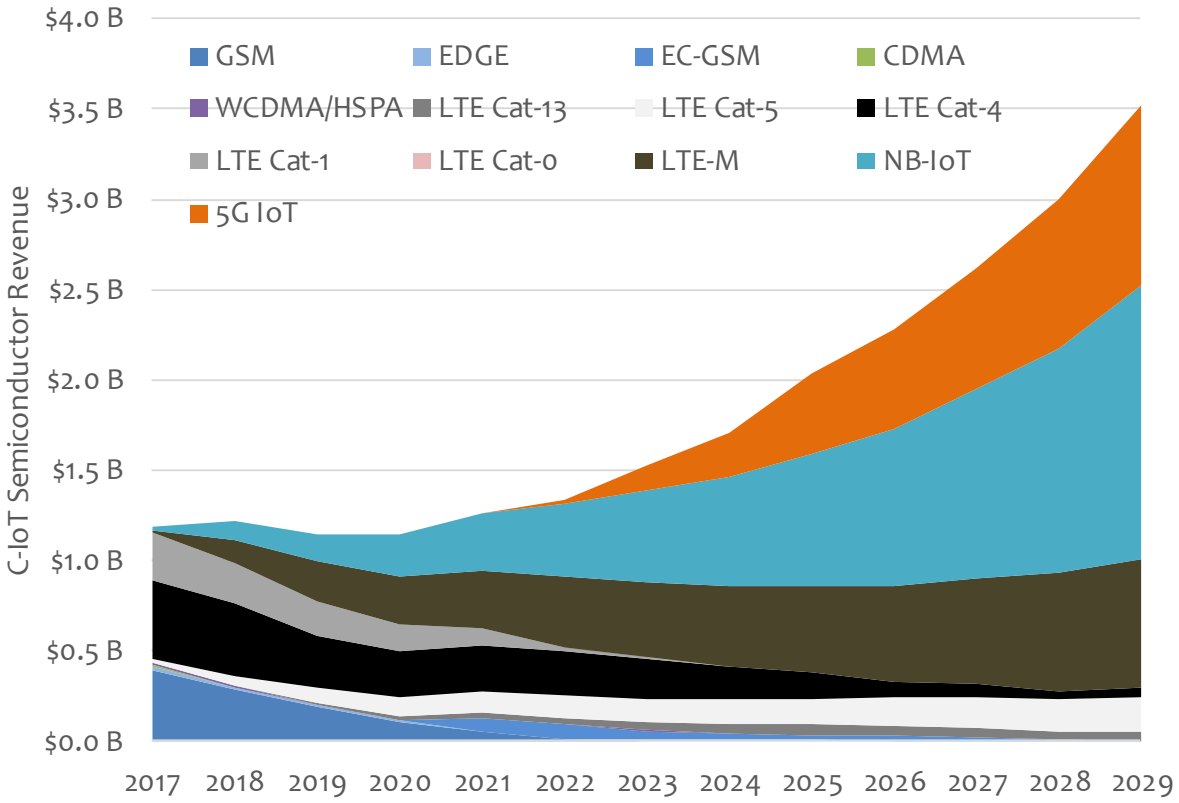


Chart 15: Cellular IoT Semiconductor Revenue, by technology standard, 2017-2029

Source: Mobile Experts

In the C-IoT semiconductor market, Qualcomm has a leading position because of its leadership in coming up with new modules quickly. However, HiSilicon (Huawei) and Sanechips (ZTE) have been very aggressive with NB-IoT chipsets, taking advantage of Chinese governments subsidies that Qualcomm, Sequans, Mediatek, and others cannot access.

Module Supplier	Chipset Vendors
Sierra Wireless	Qualcomm, Intel, Mediatek, Altair
Telit	Qualcomm, Altair
Gemalto	Qualcomm, Sequans
U-Blox	Qualcomm, internal
Simcom	Qualcomm for 3G/LTE, Mediatek for GPRS
Quectel	Qualcomm, HiSilicon
WNC	Qualcomm, Sequans, Altair
ZTE Welink	Qualcomm, Sanechips

Figure 21 Chipset suppliers used by major Cellular IoT module vendors

Source: Mobile Experts

Note that the C-IoT semiconductor market includes the semiconductors sold to module OEMs, as well as semiconductors sold for discrete C-IoT devices. Most of the cellular IoT devices on the market use modules now, but discrete devices are still used for extra band support, for some high-volume applications that are customized, and for other customization of performance.

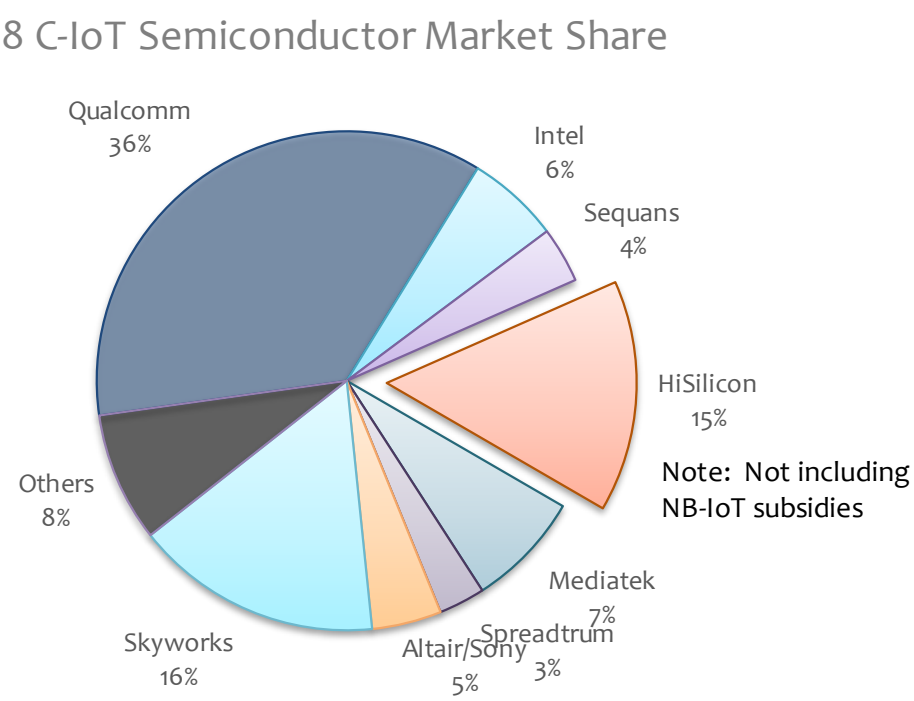


Chart 16: Cellular IoT Semiconductor Market Shares, 2018

Source: Mobile Experts. Not including PC/hotspots, GNSS. Including chips for modules and discrete IoT devices.

8 KEY COMPANIES

In the C-IoT market, of course mobile network operators are the key link in the customer chain, because they make the technical decisions about features and products. With over 500 mobile operators worldwide, we could present a very long list. Instead, we have listed some of the operators that take a leading role in developing and commercializing IoT applications:

MOBILE OPERATORS

AT&T
China Mobile
China Telecom
Deutsche Telekom
NTT DoCoMo
Orange
Softbank
Telefonica
Verizon Wireless
Vodafone

In addition to the operators, of course the OEMs and service providers that offer some kind of services to enterprise customers are clearly important. These are different in every field, with automotive OEMs, smart meter suppliers, and many other companies with specialized products in very different fields. These companies generally are not connectivity experts… they use module suppliers to insert the C-IoT function into their product.

MODULE SUPPLIERS:

DIGI INTERNATIONAL:

Digi supplies IoT devices in multiple industrial automation markets with well established customers and revenue in the range of $250M per year. The company has shipped more than 100 million IoT devices over the past 25+ years, mostly using unlicensed technology… but their cellular capability is growing and they're adding multiple new projects in transportation and retail sectors using C-IoT formats. The company provides both gateways and IoT devices for enterprise customers. Applications range from intelligent transportation systems to smart meters, temperature sensors, and grid management.

FIBOCOM

Fibocom Wireless is based in Shenzhen, and provides modules using GPRS, LTE, and NB-IoT formats. The company focuses on automotive, financial, and industrial markets and has been in operation since 2000. Relatively unknown outside of China, the company seems to have some presence in the Chinese domestic automotive and industrial markets.

GEMALTO

Gemalto is a well established IoT module supplier, but also derives a large percentage of its revenue from SIM solutions, secure software, and payment/banking solutions. The IoT module business represents a small percentage of total revenue, but it's important to Gemalto as the IoT device hardware opens up opportunities for software and security solutions. The company's strengths lie in European automotive, asset tracking, healthcare, and smart meter markets.

HUAWEI

Huawei bet big on NB-IoT with their acquisition of Neul and has successfully pushed the technology through 3GPP. Huawei has invested heavily in platforms and software for IoT modules as well as their HiSilicon chipsets. But they leave the low-margin module business to other companies. Huawei dominates the market for NB-IoT in China by surrounding the module vendors with chipsets and supporting software.

INSEEGO (NOVATEL)

Novatel Wireless established a holding company called Inseego Corporation in November 2016 to re-brand itself as a pure-play IoT services company. Inseego is the holding company for multiple brands, including Novatel Wireless (responsible for IoT modules and gateways), Ctrack, MiFi, Skyus, and DMS. The company has delivered more than 35 million IoT modules, (mostly unlicensed bands), and participates in telematics, asset tracking, broadband, industrial, and security/surveillance applications.

NEOWAY

Neoway is based in Shenzen, and supplies IoT modules ranging from simple GPRS modules to LTE, including NB-IoT modules for specific applications. They've shipped more than 36 million modules to date (mostly GPRS) The company has not been very visible outside of China but is active recently with several specialized NB-IoT applications.

QUECTEL

Quectel has enjoyed surprising growth over the last two years, with rapid deployment of new IoT modules based on Qualcomm LTE-M and NB-IoT chipsets as well as existing LTE configurations. They've also adopted the HiSilicon NB-IoT chipset for low-cost Chinese

applications. The company has reached high levels of production with more than $200M in revenue in 2018.

Sierra Wireless

Sierra Wireless is the clear leader in the IoT module area, with a strong position in the automotive, industrial, healthcare, mobile payment, asset tracking, smart meter, and other key markets and roughly 34% market share for modules. Sierra is focused on the module business but is wisely investing in growth of cloud/connectivity services.

Sunsea (SIMCom and Longsung)

Shenzen Sunsea acquired SIMCom and Longsung in 2018, putting together two weak players that were struggling financially. SIMCom has delivered large numbers of low-cost IoT modules at a loss and was unable to continue on its own, but sold at roughly its revenue value of $78M. Sunsea's intended strategy is unknown at this point.

Telit

Telit is a strong player in the C-IoT module market with revenue growth in line with the industry average in 2018. Telit has decided to sell its automotive product line for $105M, so we expect that in 2019 its market share will drop in our rankings. Telit provided about $320M of C-IoT modules in 2018 plus another $100M in IoT services and GNSS devices. Telit also participates in Wi-Fi, LoRa, and a few other unlicensed market areas.

U-blox

U-blox has grown steadily with IoT modules and GNSS positioning devices. U-Blox is the leader in GNSS modules and many of its IoT modules take advantage of that strength, with many integrated devices as well. U-Blox is a solid player in the automotive IoT area, and has products now ranging from GSM through NB-IoT as well as RPMA. Revenue has grown to about $410M in 2018 for chips and modules, and we estimate that half is devoted to GNSS modules with the other half focused on C-IoT.

WNC (Wistron Neweb)

Based in Taiwan, WNC supplies automotive, industrial, smart home, and asset tracking modules with low-cost products that lag somewhat behind the leading module suppliers but have been approved by major operators such as Verizon and AT&T. By focusing on specific markets such as the US industrial and automotive sector WNC has established a niche for itself, but its growth rate during 2018 was disappointingly flat.

ZTE

ZTE Welink is a subsidiary of ZTE which focuses on cellular IoT modules, with key relationships at operators such as AT&T, DoCoMo, SK Telecom, T-Mobile , and Verizon. ZTE boasts the smallest NB-IoT module (based on a Mediatek chipset). Using Qualcomm modem chipsets and a rapid-reaction engineering team, ZTE has the ability to introduce some features quickly and get the attention of auto manufacturers and industrial operations in the Chinese market. Finally, ZTE has its own in-house ASIC team (Sanechips) that should be able to provide silicon, but we have not seen products using Sanechips SoCs so far.

SEMICONDUCTOR SUPPLIERS:

Of course, the modules would not exist without semiconductors. 50-70%% of the module's cost can be traced back to the semiconductor devices that do the work: modems, transceivers, power amplifiers, filters, power supply devices, and other chips are key.

Key semiconductor vendors include:

ALTAIR SEMICONDUCTOR (SONY)

Altair was acquired by Sony during 2016, giving the company deeper pockets to pursue the IoT market. Altair specializes in pushing the envelope for low power and small size solutions in proprietary SoCs with minimal external components. Altair integrates baseband processor, RFIC, PMU, memory, as well as GNSS and RF functions onto a single chip to lead in small size and component count.

ARM

Of course, ARM is well known for the processor cores that take care of the computing requirements in most mobile devices. ARM is ever-present in the IoT market, as low power computing cores are required in the IoT market as much as in smartphones.

BROADCOM

Broadcom provides basic RF components for mobile handset applications, so naturally many of the Broadcom filters, power amplifiers, and other devices. Broadcom is not as focused in this area as Skyworks or Qorvo, and therefore has not achieved as many top-tier design wins for components with customized performance features. Note that Broadcom, upon merging with Avago, divested its IoT modem business to Cypress Semiconductor… so their product offering is focused on the RF side.

GCT SEMICONDUCTOR

GCT Semiconductor has launched a common single-chip solution for Cat-M and NB-IoT applications. GCT integrates RF transceiver, baseband, and memory functions but has not

pursued the integration quite as far as Altair to maintain some flexibility. Based in Korea and California, GCT has some relationships with Asian module vendors but is generally seen as a low cost chipset vendor. GCT has also introduced an interesting dual-mode C-IoT/Sigfox solution which may find interest in specialty markets.

HiSilicon (Huawei)

Huawei's level of investment in IoT has grown dramatically based on hundreds of millions of dollars in subsidies from the Chinese government to develop NB-IoT chipsets. HiSilicon, as Huawei's in-house chipset supplier, has a very rapid turnaround time for new SoC development and has chosen to use its rapid development cycle to develop separate LTE-M and NB-IoT chipset products. So far this has led to much higher market share for HiSilicon in NB-IoT, with many Chinese module vendors using HiSilicon chips with Huawei's OS and cloud platform.

Intel

Intel remains in the modem market for handsets and also provides LTE modems for IoT applications. So far Intel has introduced their XMM7315 modem for LTE-M and NB-IoT, but has not provided a low cost NB-IoT variation and frankly we don't expect them to invest so much in the low cost tier of the market. In some premium markets, Intel may have an advantage in Edge/Fog Computing with some computing migrating down to the device. Time will tell as to whether the company can successfully put together a strategy to take advantage of this kind of synergy.

Lierda

Lierda Science and Technology Group Co Ltd. Provides embedded system solutions such as Bluetooth modules and RFID. They have microcontrollers for health care, energy, and industrial control applications.

Qorvo

Qorvo is a leading RF component supplier and has a strong business for discrete devices in the RF front end of an IoT module. Between Qorvo, Broadcom, and Skyworks, the level of technology differentiation in IoT applications appears to be pretty low, so the competition for filters, power amplifiers, switches, and other RF front end devices will be more based on sales channels and focus on the IoT market than on technology. Qorvo will benefit as the market turns toward Carrier Aggregation and multi-band RF solutions.

Qualcomm

Qualcomm is a clear leader in the Cellular IoT market so far. Because Qualcomm introduces new modem chipsets earlier than other vendors, almost every module supplier uses Qualcomm's reference design as a starting point…and some move on to work with other

chipset suppliers in order to maintain a balanced portfolio. Qualcomm has also invested heavily in the RF front end, so they're the only company on our list that participates in both modem and RF markets.

Qualcomm also has invested heavily in developing software and cloud applications in key IoT vertical markets such as healthcare, smart cities, and other areas. This will become very important as Qualcomm competes with HiSilicon/Huawei providing the OS for the IoT device, as well as the cloud platform to manage the device.

SEQUANS

Sequans is a solid supplier of IoT modems and is one of the few companies that is very focused in this area. Their growth has stopped because it's becoming harder for a niche IoT chipset supplier to stand out among many other small players. Sequans has been able to develop some IoT solutions very quickly because of their focus on the IoT market, so for example they were first to market with a common Cat-M/NB-IoT modem.

MEDIATEK

Mediatek has been successful in the handset market but has seen less traction in the IoT area. That may change as Mediatek has been selected by large operators in both Japan and China for validation.

NORDIC SEMICONDUCTORS

With a strength in low-power wireless and strong market share in Bluetooth, Nordic has also entered the LTE-M and NB-IoT market with an intent to integrate for low cost. Nordic also provides the software stack for the modem as well as integration of GNSS and applications processor. Nordic supports the chipset and also integrates System-in-Package modules with RF amplifiers and other die.

RIOT MICRO

Based in Canada, RioT Micro designs chipsets for NB-ioT and LTE-M baseband chipsets in a stripped-down, highly integrated version that is modeled on Bluetooth and WI-Fi architectures for low cost. This low-cost approach may face challenges because it competes directly against the subsidized chips out of China.

SKYWORKS

Skyworks has been very focused on the IoT market and targeted early design wins with bellwether products such as Amazon's Alexa, Nest thermostats, and Fitbit smart watches. The company derives over a billion dollars (one third) of its annual revenue from non-handset applications, and we believe that roughly one third of that is actually IoT related. Only half of its IoT revenue is Cellular IoT related, as a lot of the high-profile platforms Skyworks has focused on are based on Wi-Fi.

SPREADTRUM/RDA

As a handset modem supplier, Spreadtrum has basic connectivity for LTE and offers a line of modems which can be adapted readily for IoT applications. We have not seen the kind of focused IoT strategy that Qualcomm, Altair, Sequans, and other companies have shown so we expect Spreadtrum to follow behind the market leaders with a low-cost modem product.

OTHERS (GOODIX, CEVA, EIGENCOMM, PINECONE/XIAOMI)

Several other companies are moving toward the Cellular IoT chipset market, including:

- Goodix: Bought CommSolid to add a low-power baseband stack to its biometric chipset solution.
- CEVA: We've seen the CEVA DSP core in a few NB-IoT SoC solutions so CEVA may be competitive with ARM in the low cost IoT chip market;
- Eigencomm: A start-up based in Shanghai, this company focuses on NB-IoT chipsets.
- Beijing Pinecone is a modem supplier backed by Xiaomi, and appears to be focusing first on smartphones (like Huawei) but may quickly enter the IoT market as well;

9 ACRONYMS

2G: Second Generation Cellular
3G: Third Generation Cellular
3GPP: Third Generation Partnership Project
4G: Fourth Generation Cellular
5G: Fifth Generation Cellular. Mobile Experts uses "5G" to refer to devices using a New Radio waveform
802.11: The IEEE working group for unlicensed local-area networks
802.11a: IEEE standard for broadband networking with 20 MHz channels
802.11ax: IEEE standard for broadband newtworking, up to 160 MHz channels
802.11p: Variation of IEEE standard for vehicle-to-everything communications
802.15.4: An IEEE standard which specifies PHY and MAC for low datarate personal area networks
AES-128: Advanced Encryption Standard-128 bit
ARPD: Average Revenue Per Device
ASK: Amplitude Shift Key modulation
ASP: Average Selling Price
BLE: Bluetooth Low Energy
Bps: bits per second
BLE: Bluetooth Low Energy (Bluetooth 4.0+)
BT: Bluetooth
C-IoT: Cellular Internet of Things
Cat-13: LTE Category 13. In this report "Cat-13" devices refer to the uplink standard.
Cat-5: LTE Category 5 In this report "Cat-5" devices refer to the uplink standard.
Cat-4: LTE Category 4
Cat-1: LTE Category 1
Cat-0: LTE Category 0
Cat-M: LTE Cat-m1, also known as LTE-M
Cat-m1: LTE Category m1, commonly called LTE-M
Cat-m2: NB-IoT as referenced in 3GPP
Cat-NB1: The NB-IoT or Narrowband Internet of Things standard as referenced in 3GPP
Cat-NB2: An anticipated followon to NB1
CDMA: Code Division Multiple Access
dBm: A measurement of radio signal strength
EC-GSM: Extended Coverage GSM
eMTC: Enhanced Machine-Type Communications (also called LTE-M)
FCC: Federal Communications Commission (USA)
FSK: Frequency Shift Key modulation
GFSK: Gaussian Frequency Shift Keying modulation
GHz: Gigahertz
GM: General Motors
GMSK: Gaussian Minimum Shift Keying modulation
GNSS: Global Navigational Satellite System

GPRS: General Packet Radio Service
GPS: Global Positioning System
GSM: Global System for Mobile (2G cellular standard)
Hz: Hertz
IoT: Internet of Things
IPv6: Internet Protocol version 6
ISM: Instrumentation, Scientific, and Medical (a designation for unlicensed spectrum)
J3016: SAE International standard for automated driving reference
Kbps: kilobits per second
kHz: Kilohertz
LAN: Local Area Network
LNA: Low Noise Amplifier
LoRa: Long Range (a low power, wide area wireless format)
LPWA: Low Power Wide Area communications
LTE: Long Term Evolution (a 4th generation cellular standard)
LTE-M: LTE Category-M1 standard (for machine communications)
LTE-V: LTE adapted for vehicles
M2M: Machine-to-machine communications
Mbps: Megabits per second
MCU: Microcontroller Unit
MHz: Megahertz
mW: milliwatts of power
NB-IoT: Narrowband IoT (a 3GPP based wireless standard)
OBU: On Board Unit
OFDM: Orthogonal frequency division multiplexing
PA: Power Amplifier
PHY: Physical layer of a system
PLC: Power Line Communications
QAM: Quadrature Amplitude Modulation
RSU: Road Side Unit
UNII-4: Unlicensed National Information Infrastructure, 4th band
V2I: Vehicle to Infrastructure
V2V: Vehicle to Vehicle
V2X: Vehicle-to-everything
W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface
WAN: Wide Area Network
Wi-Fi: Wireless Fidelity (refers to the broad family of 802.11 standards)

10 METHODOLOGY

Mobile Experts investigates the IoT market in two distinct ways, in order to compare the results and create the most accurate forecast possible.

1. First, Mobile Experts investigates the market according to vertical market segments. We publish a series of market study documents on eight vertical markets throughout the year. Each of these studies involves at least 25 interviews with key vertical market players:
    a. Utility Meters
    b. Healthcare and Fitness Devices
    c. Automotive IoT
    d. Asset Tracking
    e. Industrial IoT
    f. Smart Cities
    g. Agriculture
    h. Security/Building Automation
2. We also investigate the number of devices used in each technology area. For example, in the automotive market, we have interviewed Ford, GM, Honda, Toyota, Mitsubishi, Kia, Daimler, and BMW in order to chart the use of various LTE modes in the automotive sector. We interviewed a similar list of OEMs in the smart meter market. We check the OEM inputs in our interviews with direct input from semiconductor and module vendors, to verify that the two data sources agree with each other. We routinely interview about 15-20 IoT semiconductor suppliers related to various markets in order to verify pricing, market shares, and shipment numbers.

Mobile Experts estimated the pricing and revenue of C-IoT modules by technology (Cat-4, Cat-1, LTE-M, etc.) and then separately estimated pricing/revenue by application (automotive, healthcare, industrial, etc.). We adjusted our module pricing assumptions until these two estimates matched within 5%. In this way, we arrived at average market prices instead of using only the anecdotal data obtained from suppliers.

Overall, Mobile Experts compares the technology-based forecast with the vertical market forecast, in order to validate each approach. When these two methods do not match, we do more direct investigation with suppliers in the industry to determine why they are different.

Note that the Mobile Experts forecast figures for module revenue by air interface standard do not match exactly with the module revenue by application. This comes from our two-pronged investigation in which we develop the forecast from two different starting points, in order to assure overall accuracy in the fast-changing IoT market. We do not consider the precision of our <5% difference to be meaningful in our overall forecast.